KamLAND-Zen
の状況と展望

禅

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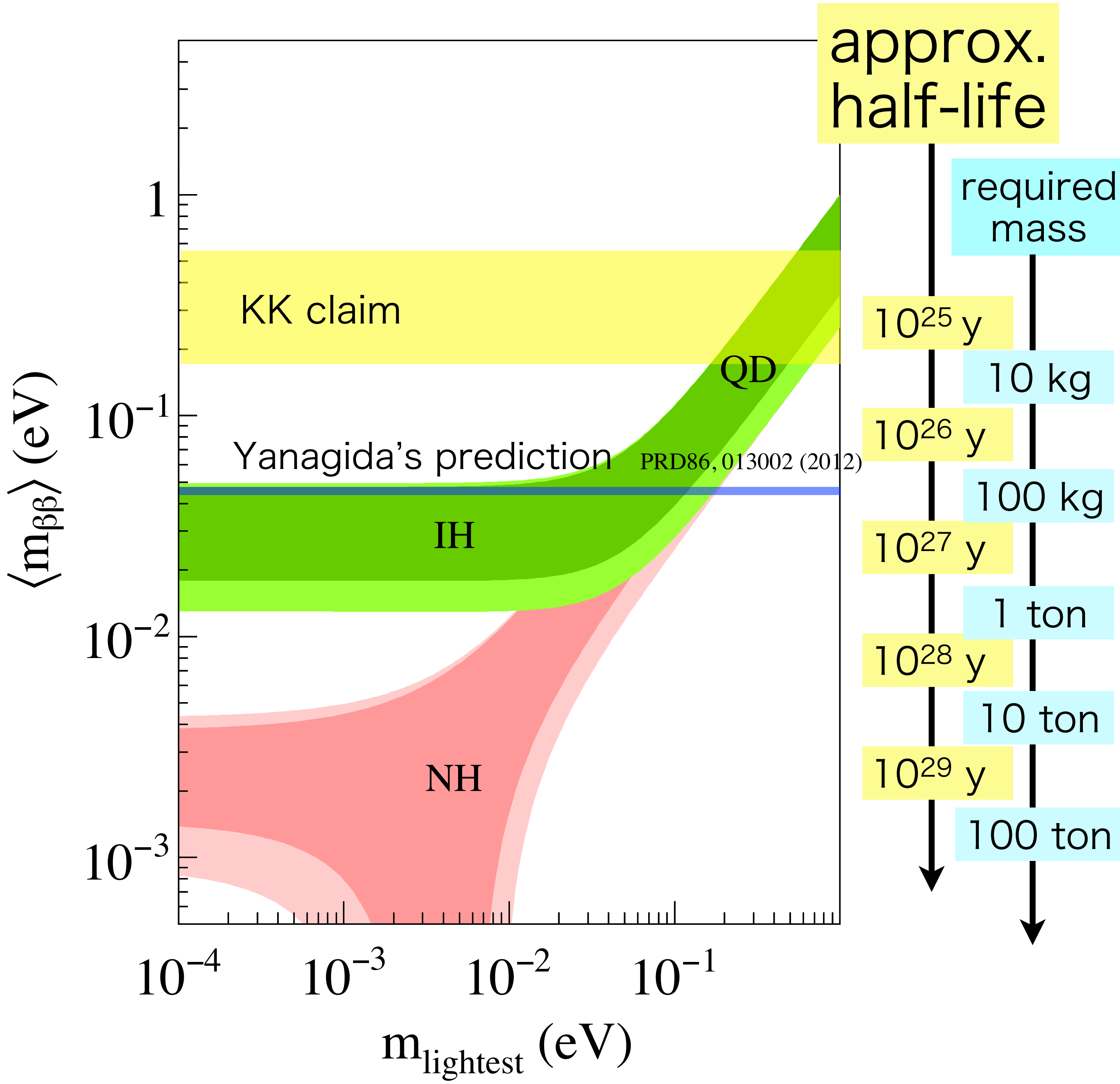
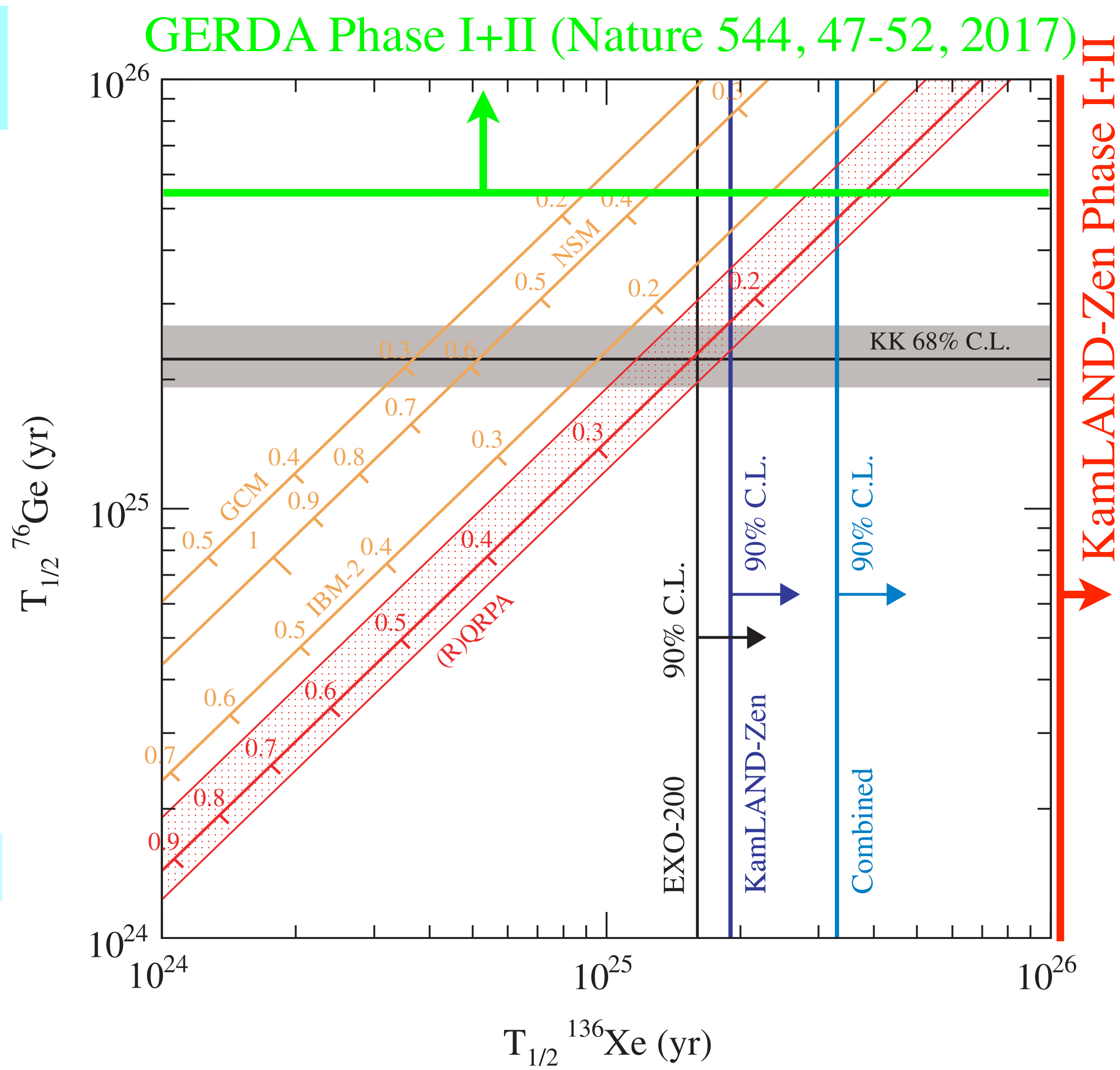
「宇宙の歴史をひもとく地下素粒子原子核研究」2017年領域研究会
2017年5月21日、岡山大学50周年記念館

Milestone





Experimental milestone has been a verification of KK-claim.

KL-Zen+EXO-200 refuted it with fairly robust NME assumption.

GERDA then clearly rejected it using the same ^{76}Ge.

What's next?

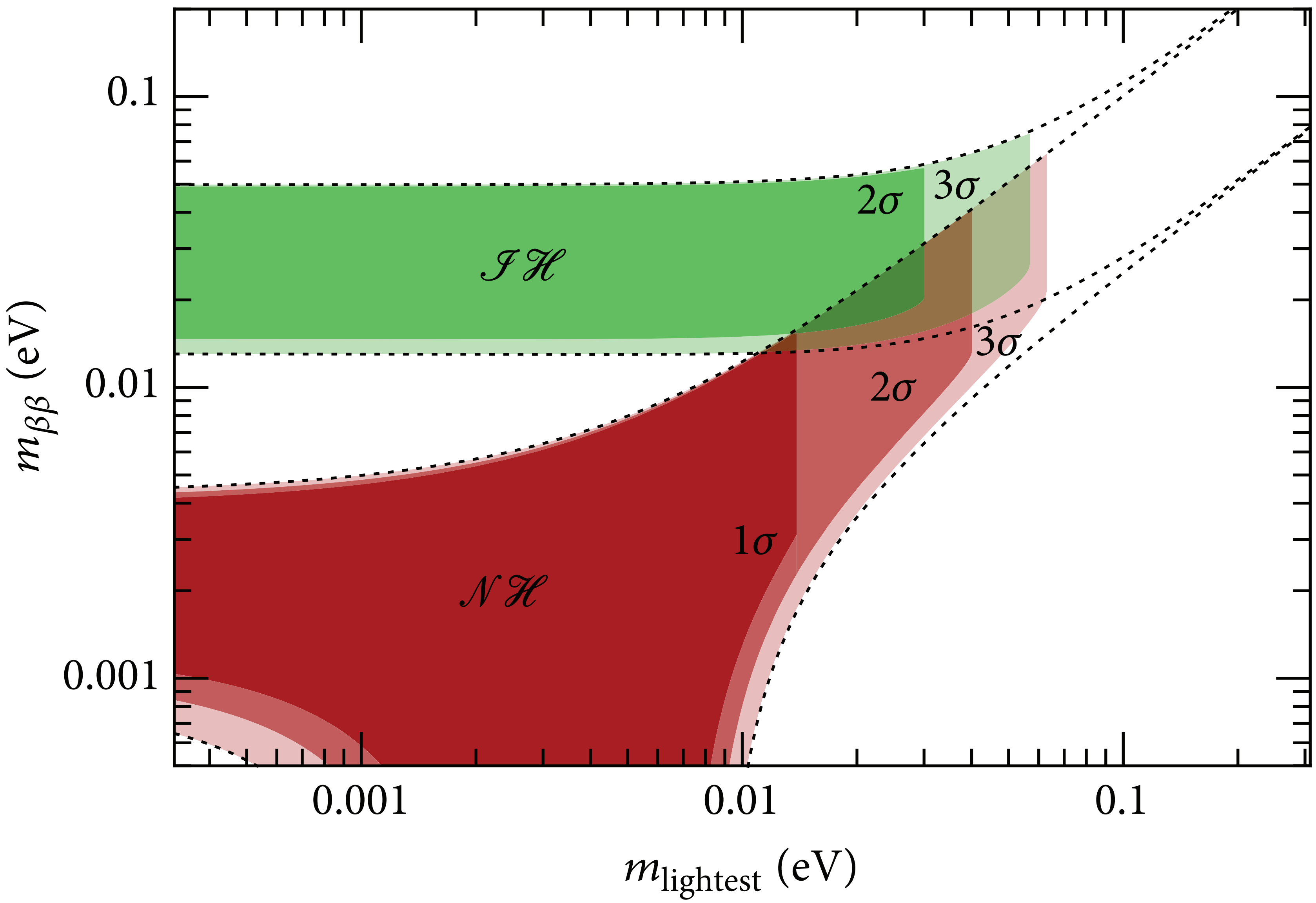
full coverage of Quasi Degeneracy → next milestone

full coverage of Inverted Hierarchy → next gen. exp.

full coverage of $m_{lightest}$~0 (below 1 meV) → very difficult

Allowed region from Oscillation and Cosmology

Dell'Oro et al., Advances in High Energy Physics 2016, 2162659



We need to propose a future plan seeking below 10 meV.

comparison of double beta decay nuclei

Rodin et al., Nucl. Phys. A793 (2007)213-215

Nucleas	$T^{0\nu}_{1/2}$(50 meV)	$T^{2\nu}_{1/2}$ measured (year)	Nat. Abundance (%)	Q-value (keV)	
$^{48}Ca \rightarrow ^{48}Ti$		$(4.2^{+2.1}_{-1.0}) \times 10^{19}$	0.19	4272	max. Q、fast 2ν
$^{76}Ge \rightarrow ^{76}Se$	0.86×10^{27}	$(1.5 \pm 0.1) \times 10^{21}$	7.8	2039	semiconductor
$^{82}Se \rightarrow ^{82}Kr$	2.44×10^{26}	$(0.92 \pm 0.07) \times 10^{20}$	9.2	2995	
$^{96}Zr \rightarrow ^{96}Mo$	0.98×10^{27}	$(2.0 \pm 0.3) \times 10^{19}$	2.8	3356	
$^{100}Mo \rightarrow ^{100}Ru$	2.37×10^{26}	$(7.1 \pm 0.4) \times 10^{18}$	9.6	3034	fast 2ν
$^{116}Cd \rightarrow ^{116}Sn$	2.86×10^{26}	$(3.0 \pm 0.2) \times 10^{19}$	7.5	2814	
$^{128}Te \rightarrow ^{128}Xe$	4.53×10^{27}	$(2.5 \pm 0.3) \times 10^{24}$	31.7	866	
$^{130}Te \rightarrow ^{130}Xe$	2.16×10^{26}	$(0.9 \pm 0.1) \times 10^{21}$	34.5	2527	large nat. abundance
$^{136}Xe \rightarrow ^{136}Ba$	4.55×10^{26}	$(2.3 \pm 0.1) \times 10^{21}$	8.9	2458	slow 2ν, rare gas
$^{150}Nd \rightarrow ^{150}Sm$	2.23×10^{25}	$(7.8 \pm 0.6) \times 10^{18}$	5.6	3371	0ν, fast 2ν

Notable nuclei

^{48}Ca highest Q, isotope enrichment is an issue

^{76}Ge semiconductor

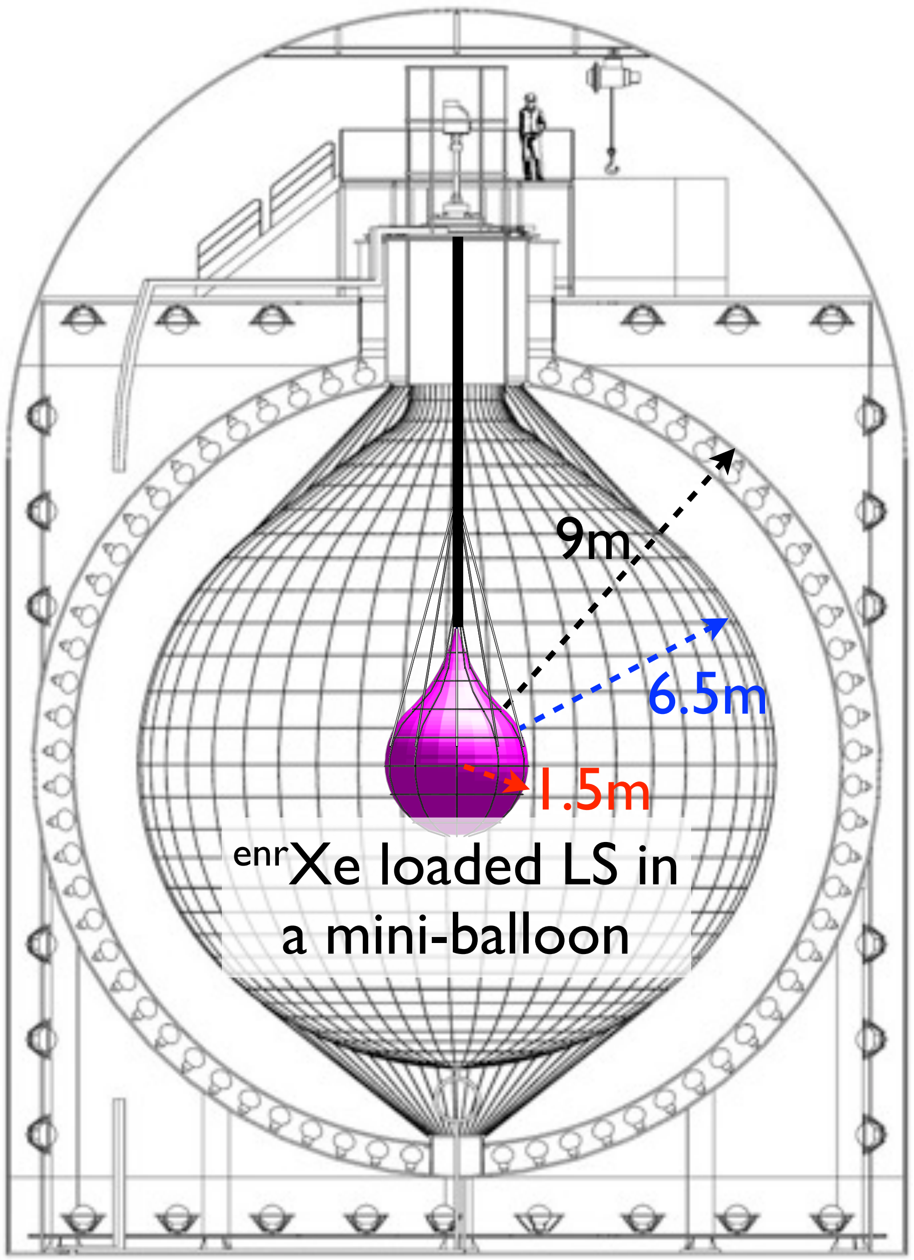
^{136}Xe easy enrichment / purification, various detector technology

^{130}Te high natural abundance

^{150}Nd fast 0ν

KamLAND-Zen

Zero Neutrino
double beta decay search

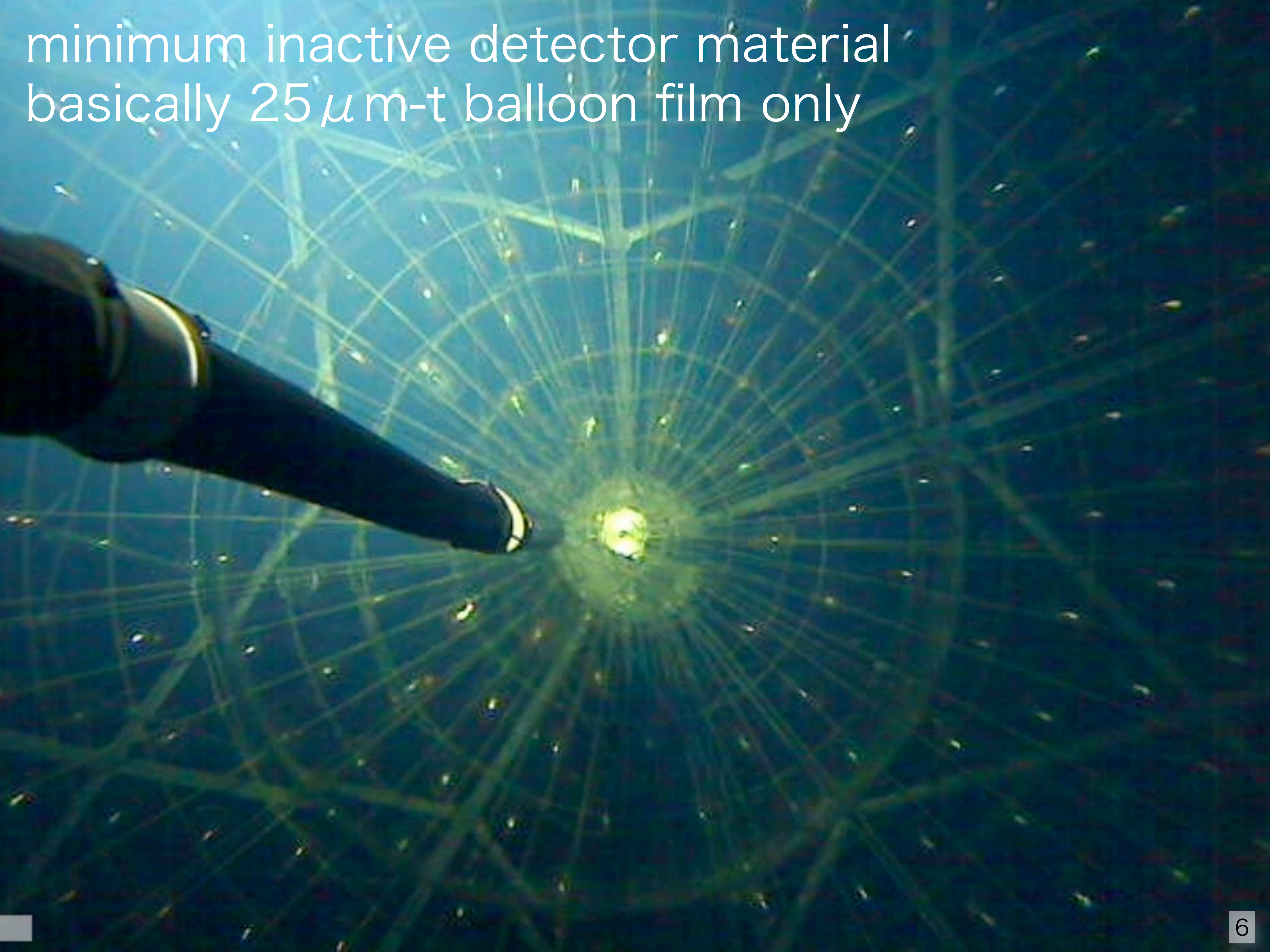


Advantages of using KamLAND

- running detector
  → relatively **low cost and quick start**
- huge and clean (1200m^3, U: 3.5x10^{-18} g/g, Th: 5.2x10^{-17})
  → negligible external gamma

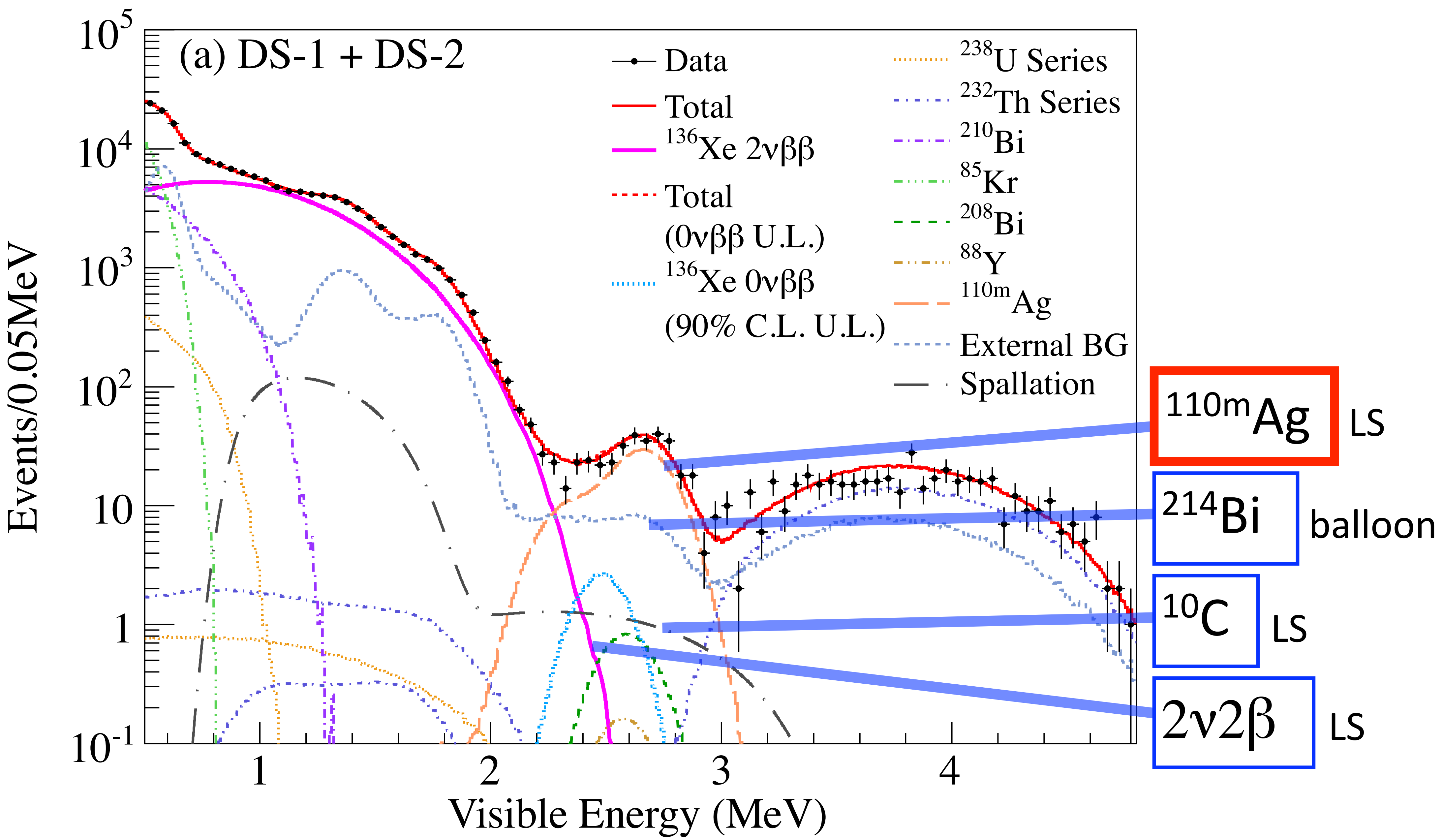
  (Xe and mini-balloon need to be clean)
- **Xe-LS can be purified**, mini-balloon replaceable if necessary, with relatively low cost
  → highly scalable (up to several tons of Xe)
- No escape or invisible energy from β, γ
  → BG identification relatively easy
- **anti-neutrino observation continues**
  → geo-neutrino w/o Japanese reactors

320kg 90% enriched ^{136}Xe installed for phase-I and 380kg for phase-II


minimum inactive detector material
basically 25 μm-t balloon film only

KamLAND-Zen started in 2011

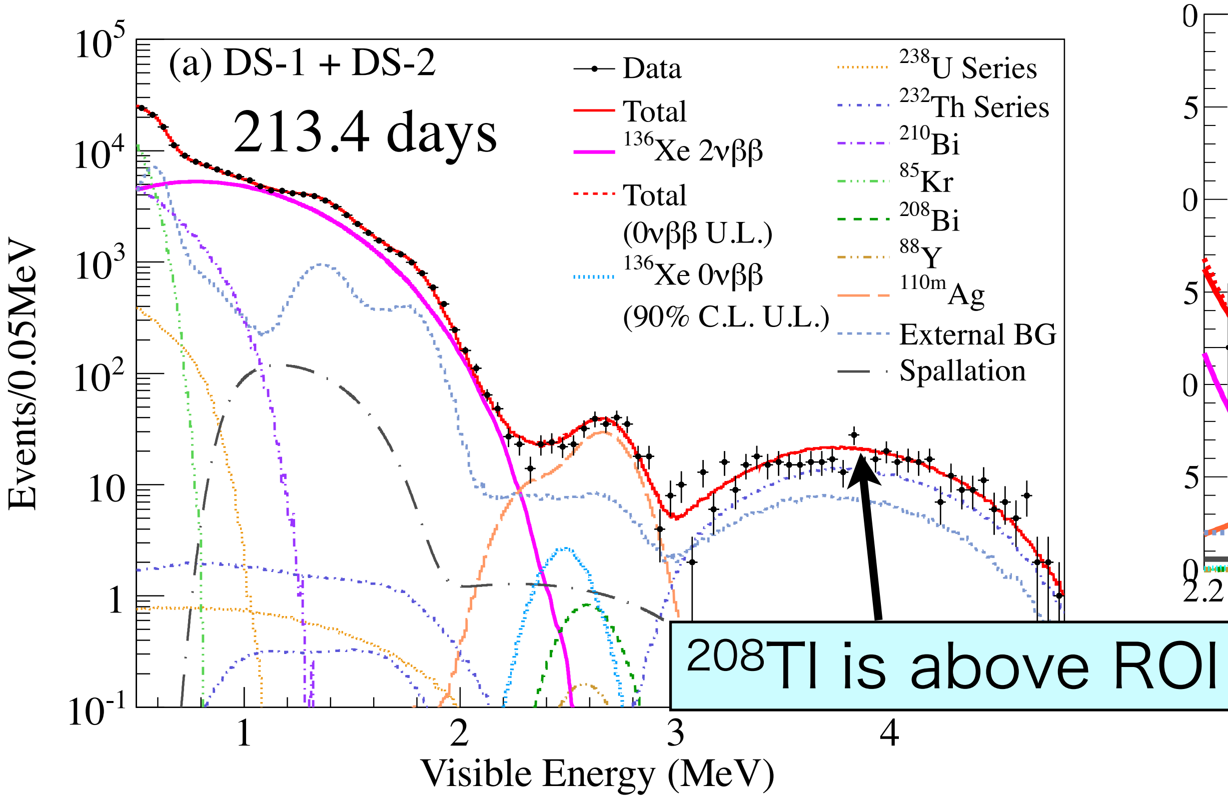
only 2 years from initial funding (quick start!)



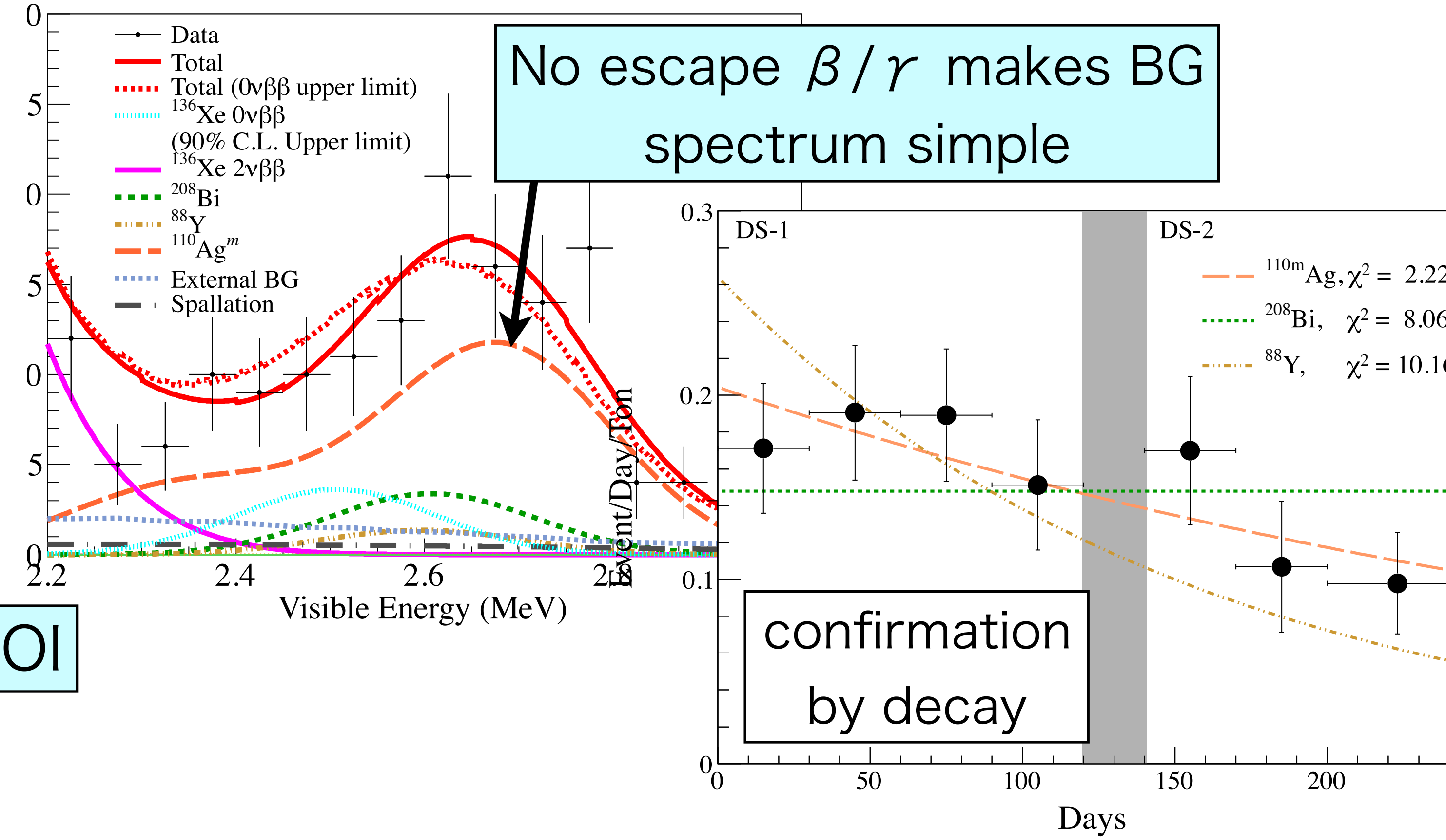
Unexpected BG has found

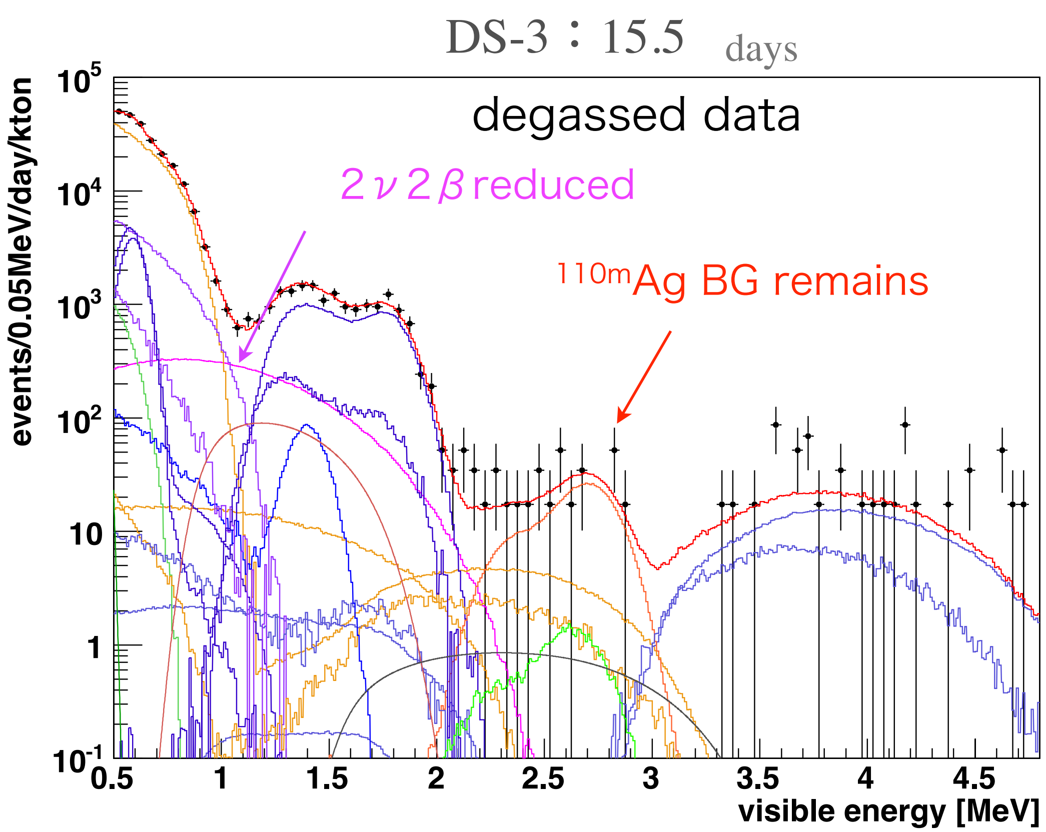
KamLAND-Zen Phase I (320kg xenon loading)

Thanks to full active apparatus,



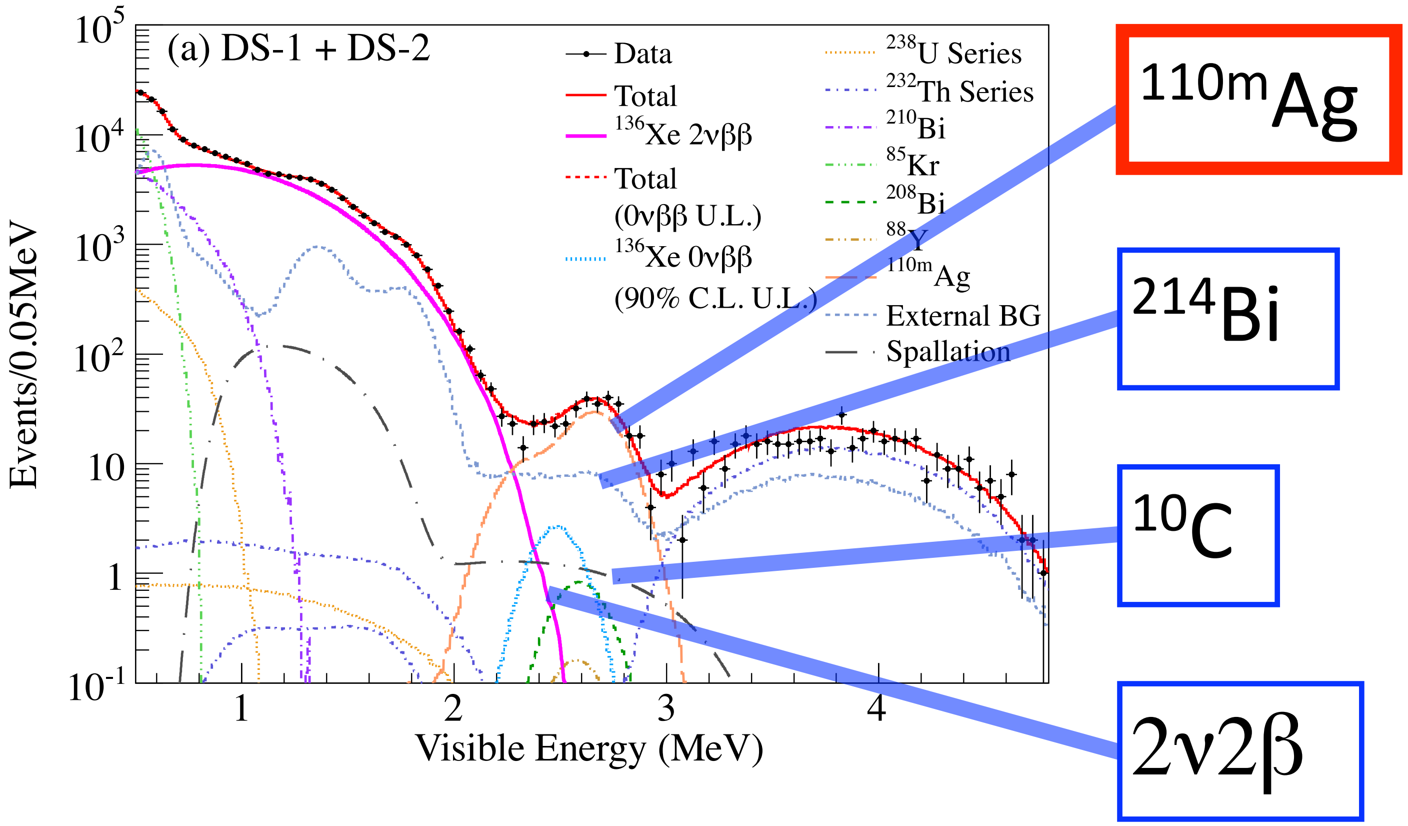
Dominant BG identified as ^{110m}Ag





Xenon can be degassed from Xe-LS.
And ^{136}Xe on/off measurement has been demonstrated.
(useful for signal confirmation)

What can we do?



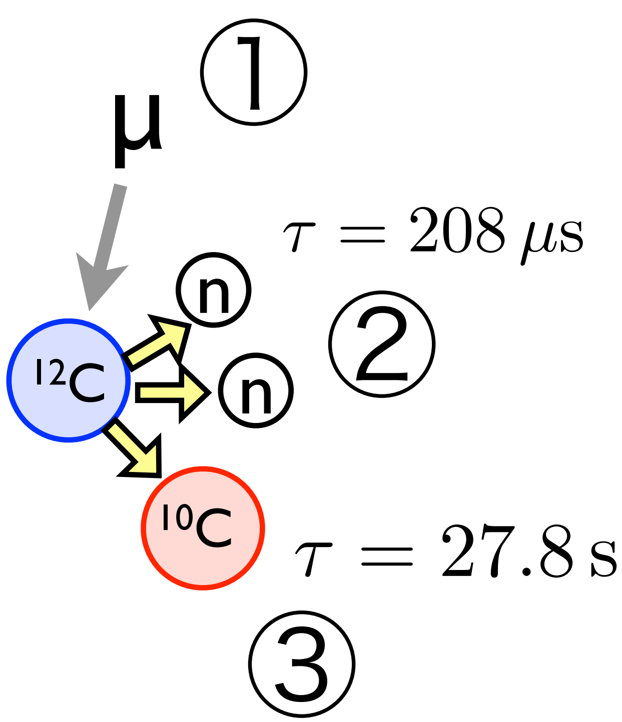
purification !!

fine binning of volume

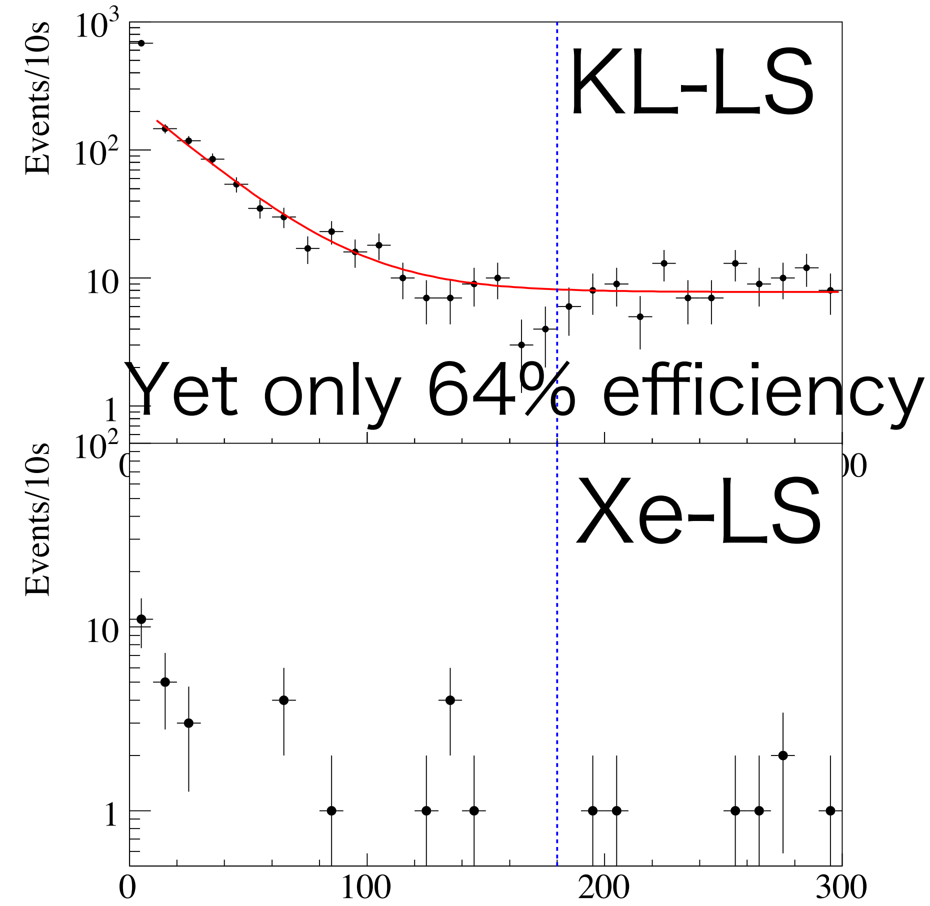
triple fold coincidence

future task

tripe fold coincidence
for ^{10}C rejection

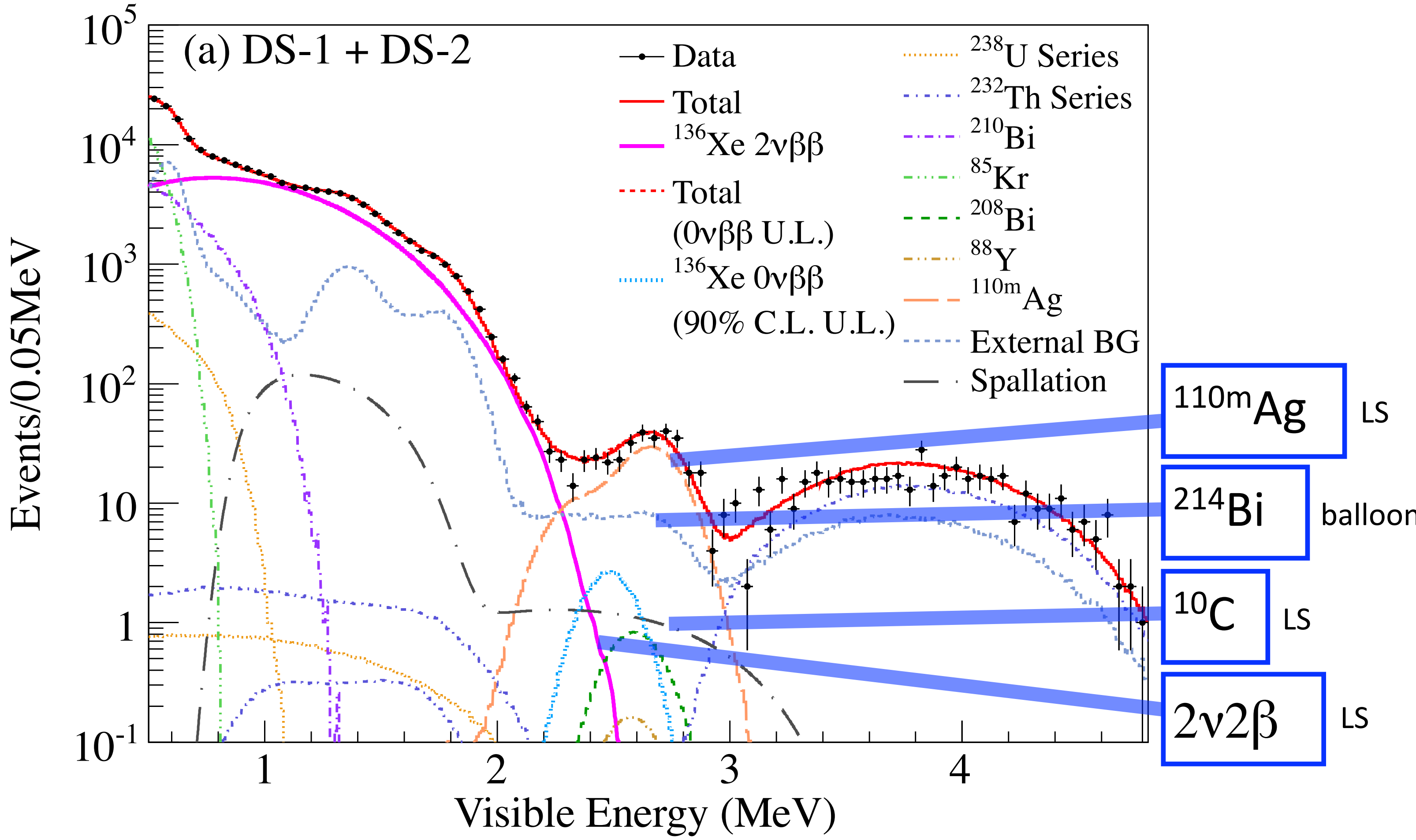


dead time free electronics MoGURA



Phase-1 320kg

before purification

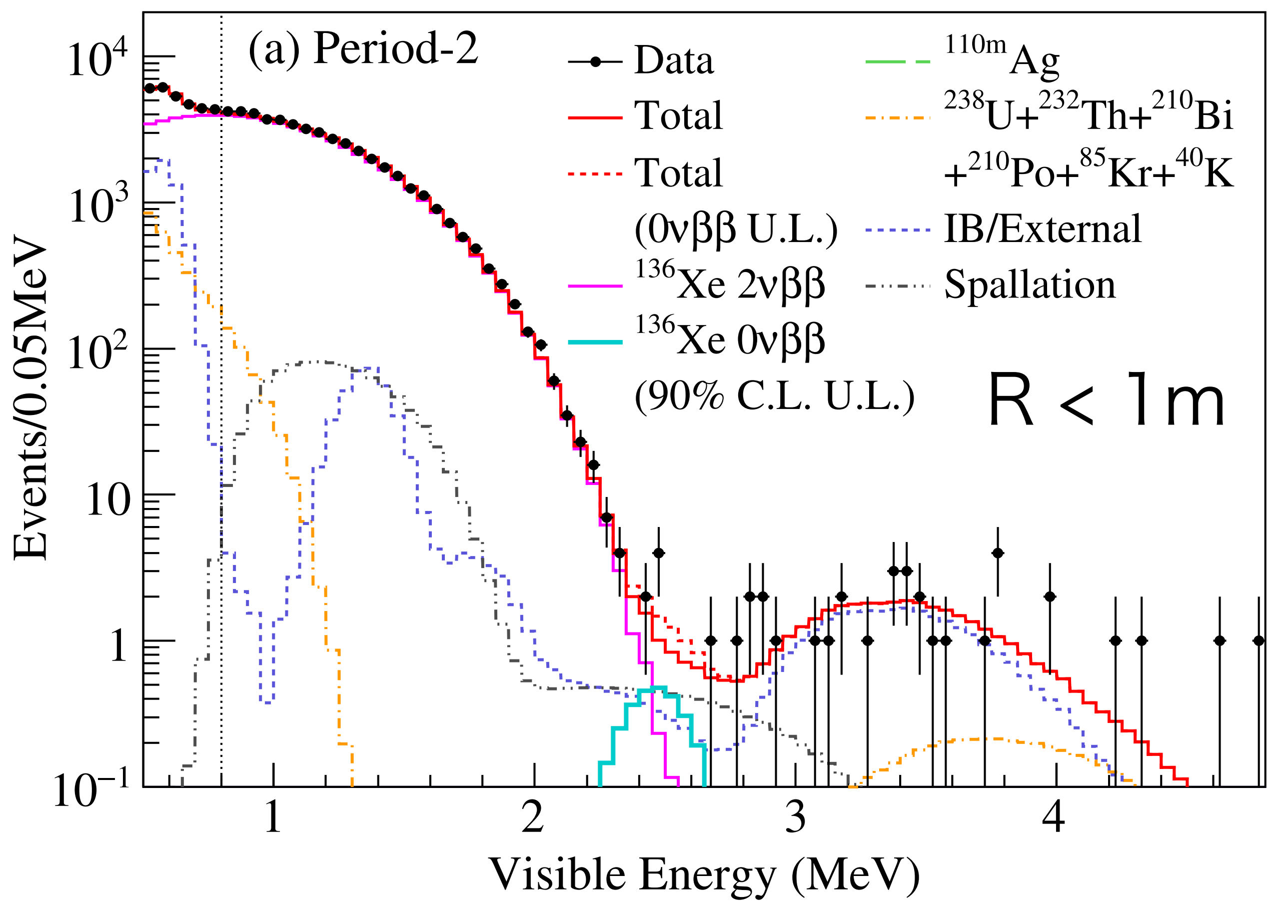


>1.9x10^{25}y

Phase-2 380kg

after purification

^{110m}Ag reduction <1/10



2013/12/11 - 2014/10/27

534.5 days (504 kg-yr)

(cf. $T_{1/2}$(^{110m}Ag)=250 days)

in-situ purification possible!!

Event summary   2.3 < E < 2.7 MeV, R < 1 m

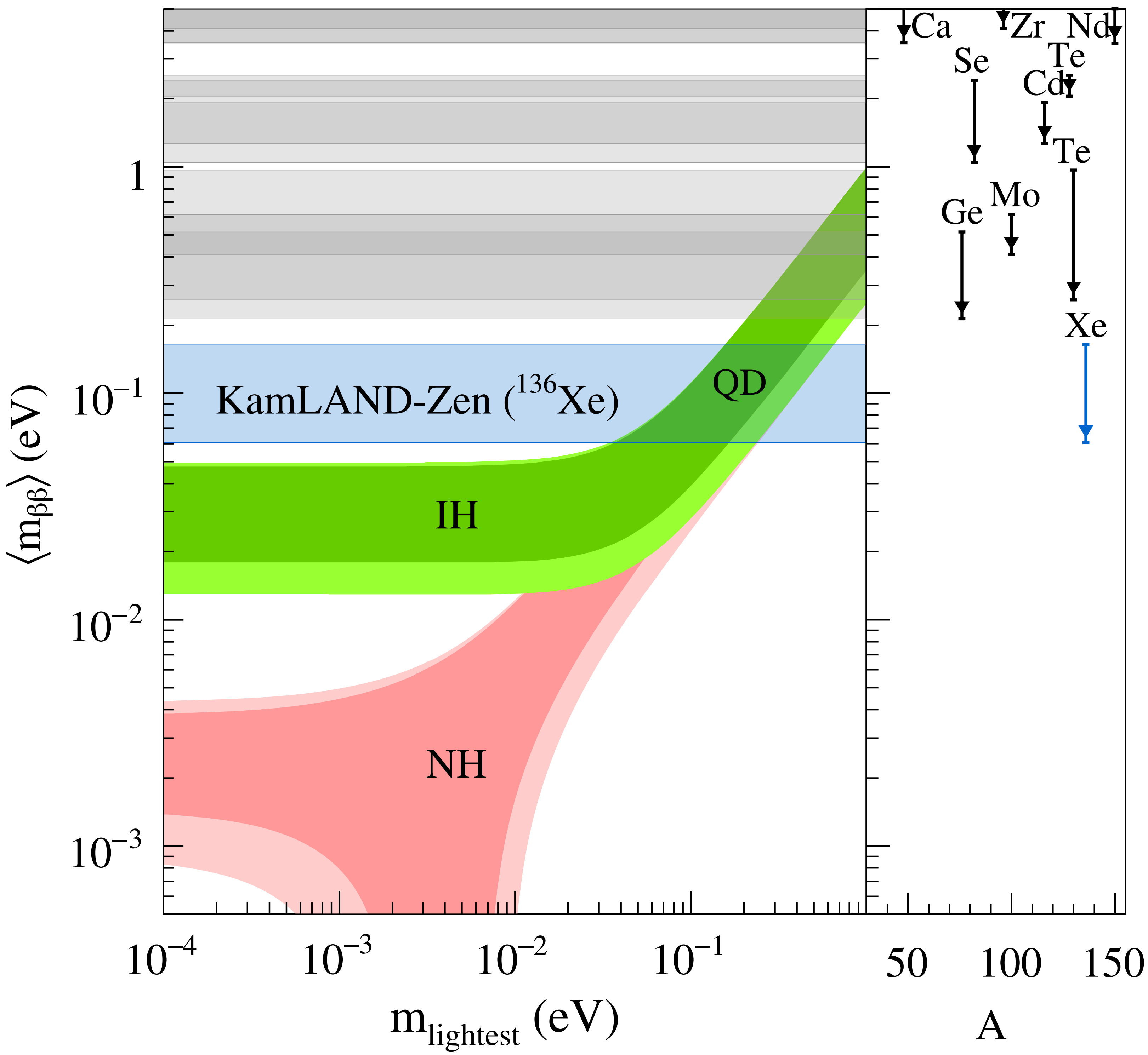
	Period-1 (270.7 days)		Period-2 (263.8 days)	
Observed events	22		11	
Background	Estimated	Best-fit	Estimated	Best-fit
^{136}Xe $2\nu\beta\beta$	···	5.48	···	5.29
Residual radioactivity in Xe-LS				
^{214}Bi (^{238}U series)	0.23 ± 0.04	0.25	0.028 ± 0.005	0.03
^{208}Tl (^{232}Th series)	···	0.001	···	0.001
^{110m}Ag	···	8.5	···	0.0
External (Radioactivity in IB)				
^{214}Bi (^{238}U series)	···	2.56	···	2.45
^{208}Tl (^{232}Th series)	···	0.02	···	0.03
^{110m}Ag	···	0.003	···	0.002
Spallation products				
^{10}C	2.7 ± 0.7	3.3	2.6 ± 0.7	2.8
^{6}He	0.07 ± 0.18	0.08	0.07 ± 0.18	0.08
^{12}B	0.15 ± 0.04	0.16	0.14 ± 0.04	0.15
^{137}Xe	0.5 ± 0.2	0.5	0.5 ± 0.2	0.4

Phase-1 & 2 combined limit

!!!

$$T^{0\nu}_{1/2} > 1.07 \times 10^{26}\ \mathrm{yr}$$

$$\langle m_{\beta\beta} \rangle < (61 - 165)\ \mathrm{meV}$$



It also provides upper limit of $m_{lightest}$ at 180-480 meV.

Big leap toward IH !!

Our challenge continues!

Three dominant BGs; 2ν, "^{214}Bi on the film" and ^{10}C.

next target

further optimization of triple-fold coincidence and shower detection

We have purchased 800 kg of enriched xenon in total.

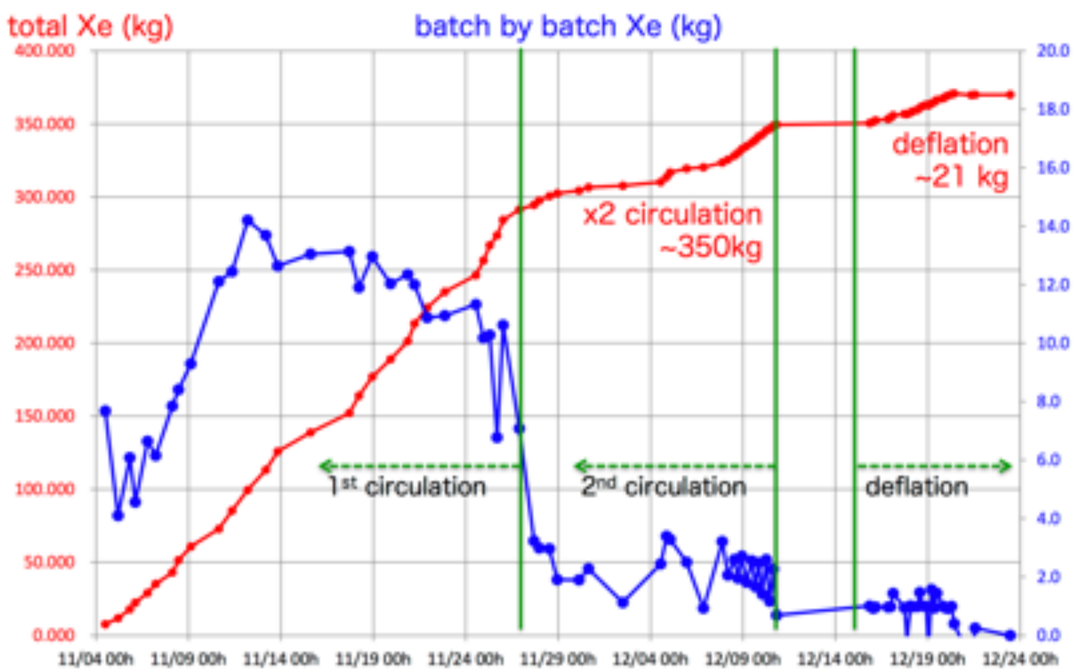
We have fabricated a larger mini-balloon with better measures against dusts.

We will resume the search with 750 kg of xenon.
To be called as "KamLAND-Zen 800".

(Expected sensitivity is below 50 meV hoping to cover Yanagida's prediction.)

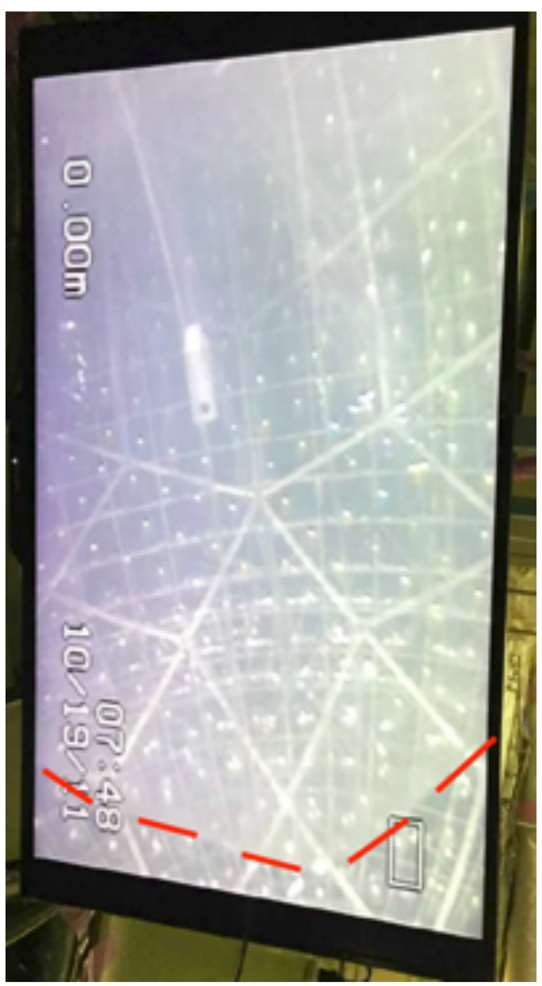
Mini-balloon has been extracted. (Dec. 2015)

Zen 400

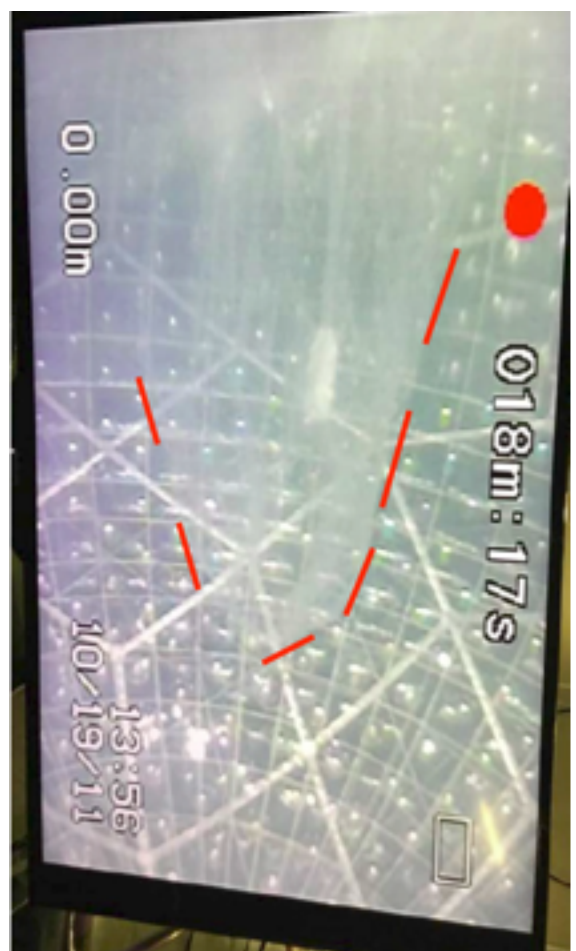


for tank investigation required by law

Xenon has been recovered during recirculation and deflation of the mini-balloon.



deflation



2nd mini-balloon fabrication

cleaning, cleaning and cleaning as usual

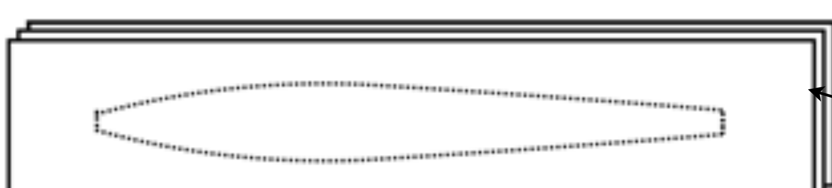
Example of improvements

before

after

clean underwear

changing room in a clean room

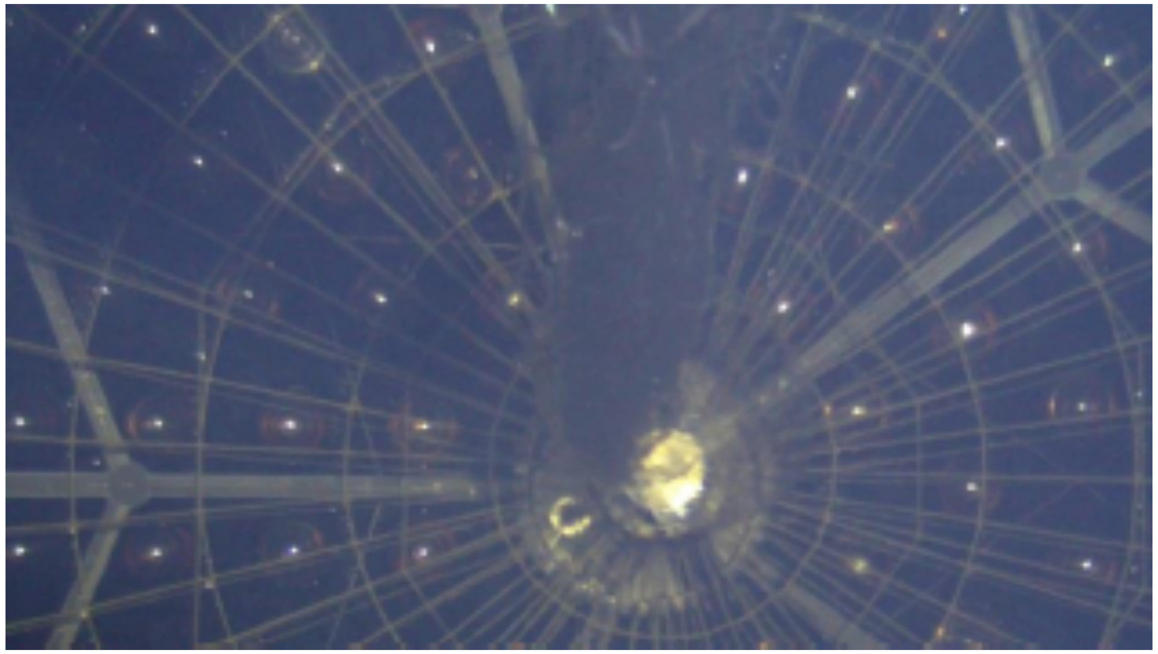


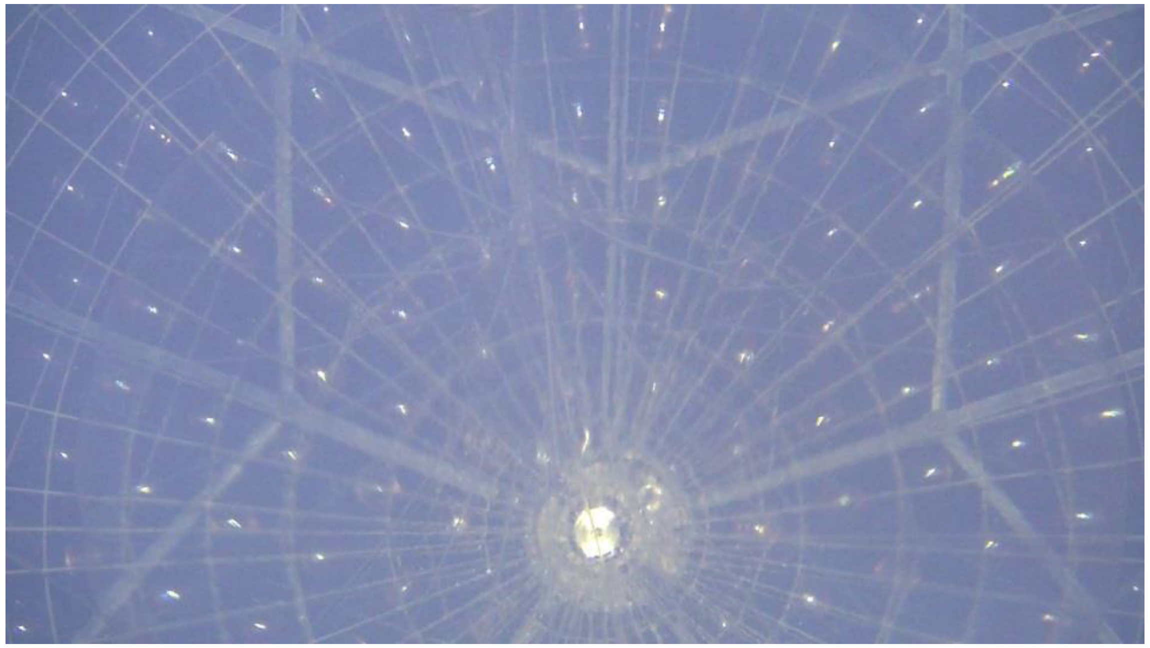
cover sheets

keep staying away
goggle
welding machine
cover sheet .
glove on glove
laundry twice a day .
clean underwear .
changing room in a clean room .
dust visualization
more neutralizer
. . .

laundry twice a day

after Leak check and repair





New mini-balloon has been deployed and inflated with "dummy" LS in last August

through characterization of mini-balloon

We confirmed that the mini-balloon is cleaner !!

Measures we took worked!

preliminary

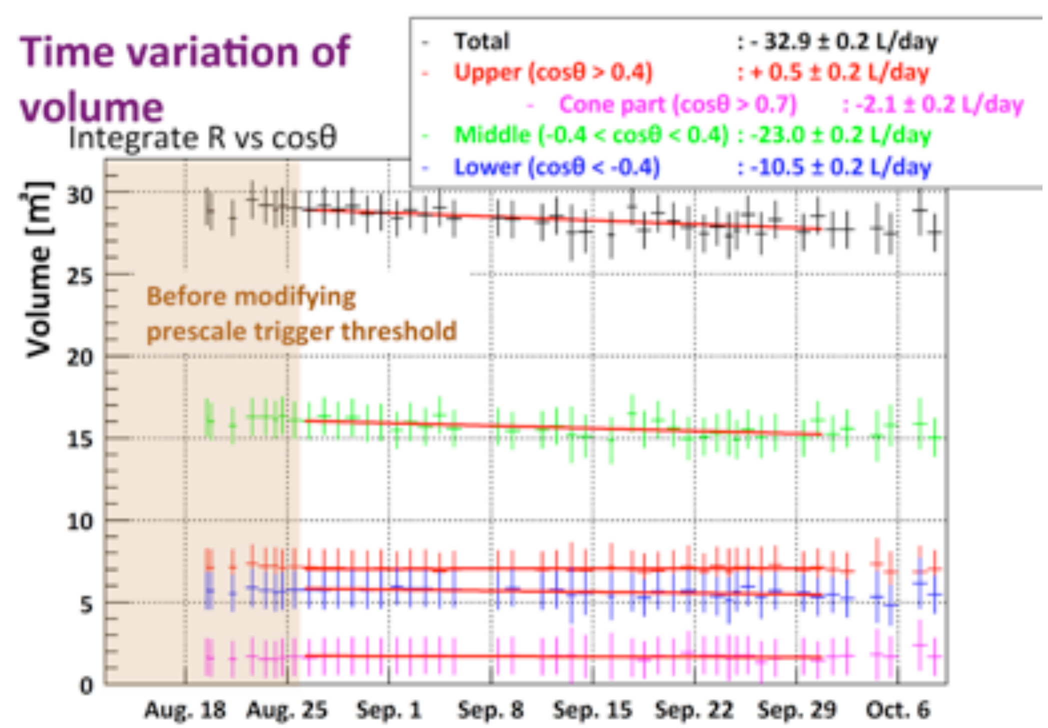
x1E-12 g/g_{film}	^{232}Th	^{238}U
洗浄直後	6	2 Target
This time*	31+-7	5.3+-0.8
Zen 400 1st	79+-3	14+-1
Zen 400 2nd	336+-2	46.1+-4

~1/10

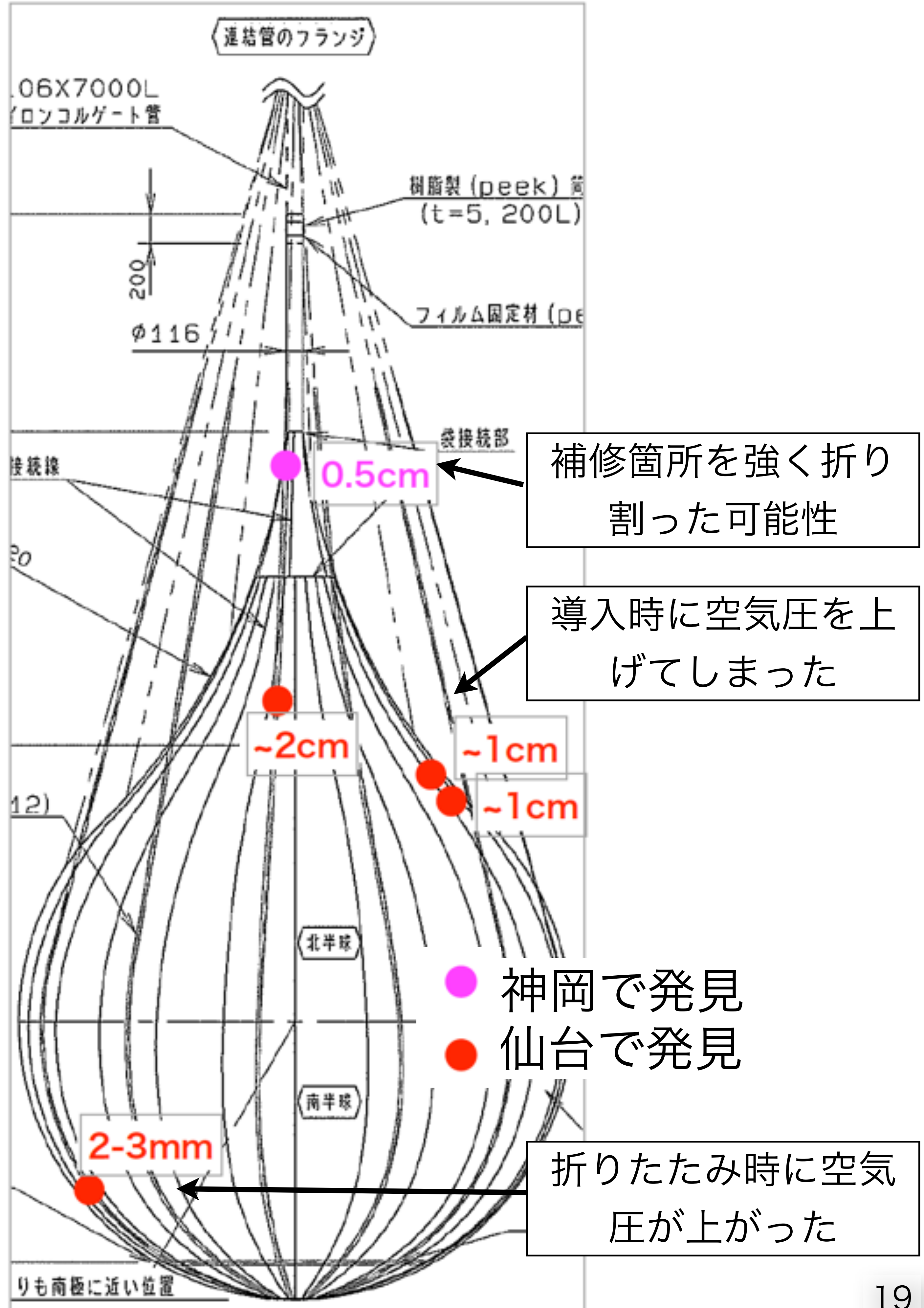
At the same time, we noticed;

Indications of leak;

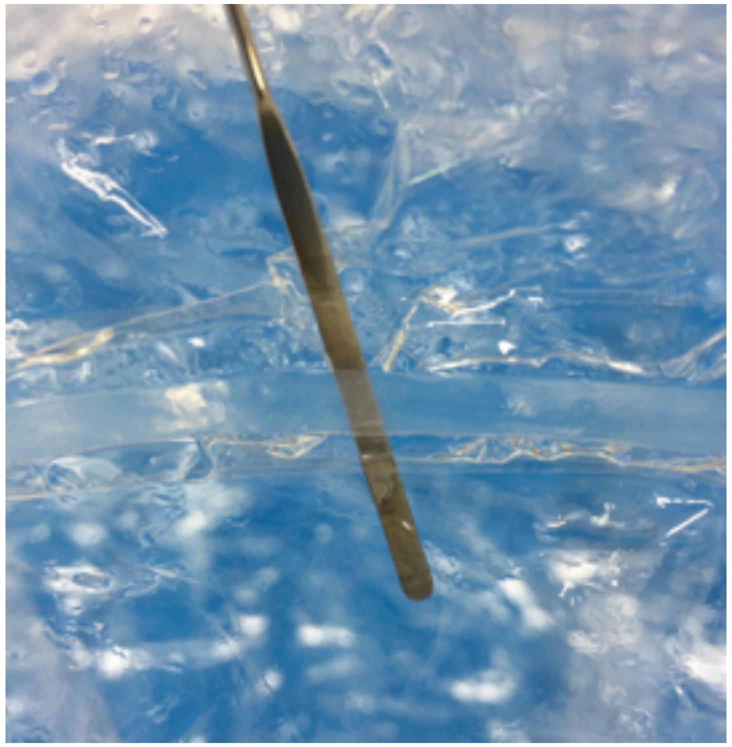
- camera image
- load cell
- balloon shape reconstruction with ^{210}Po events
- ^{222}Rn decay rate
- mixture of KL-LS and dummy-LS by gas-chromatography



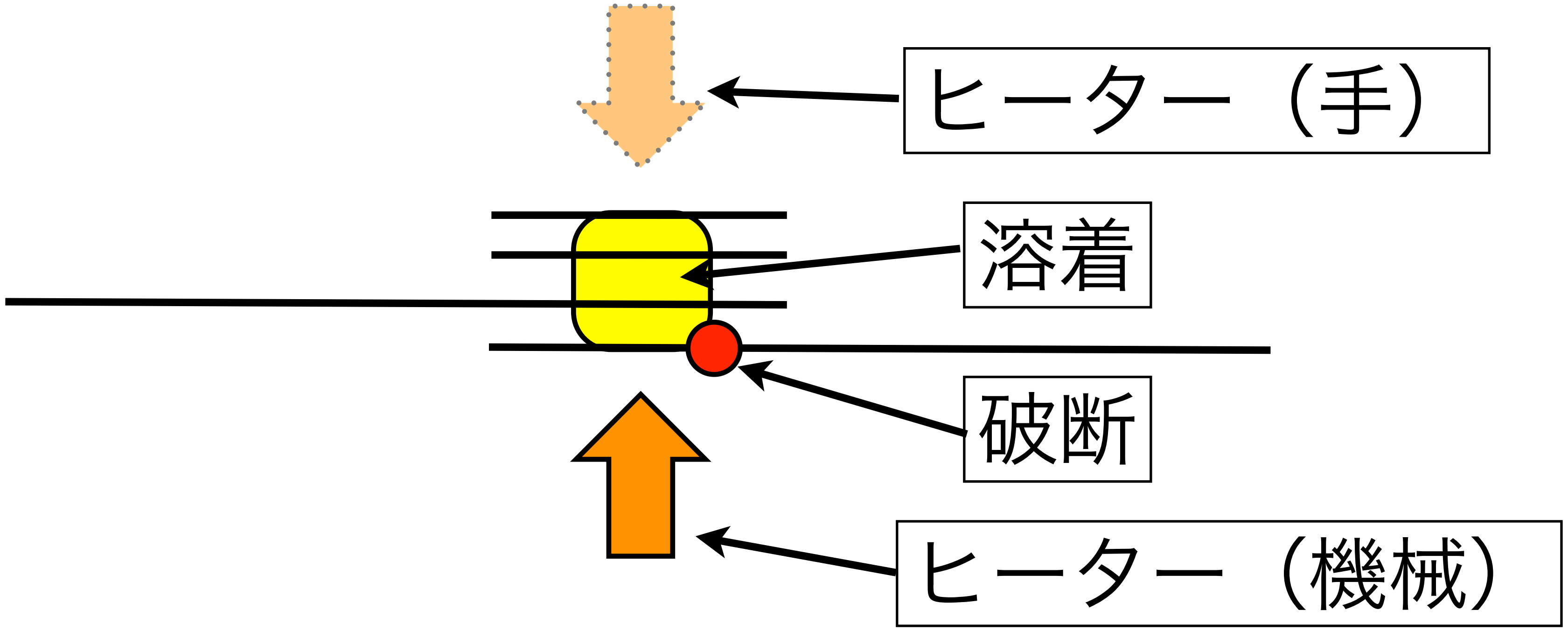
回収したミニバルーンをHeリーク検出器で調べた。

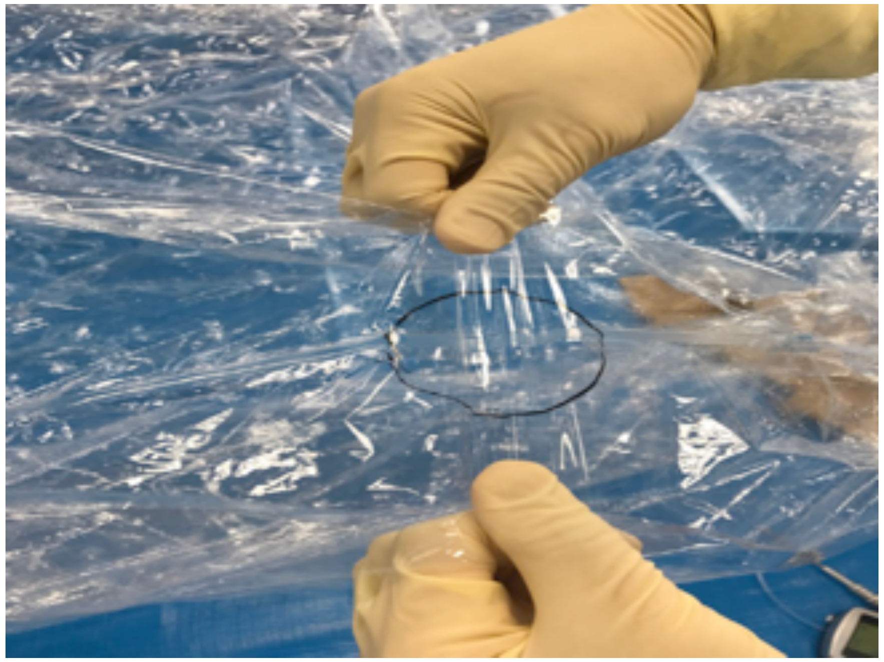


補修した溶着部が割れている。



機械溶着ラインの端が避けている。





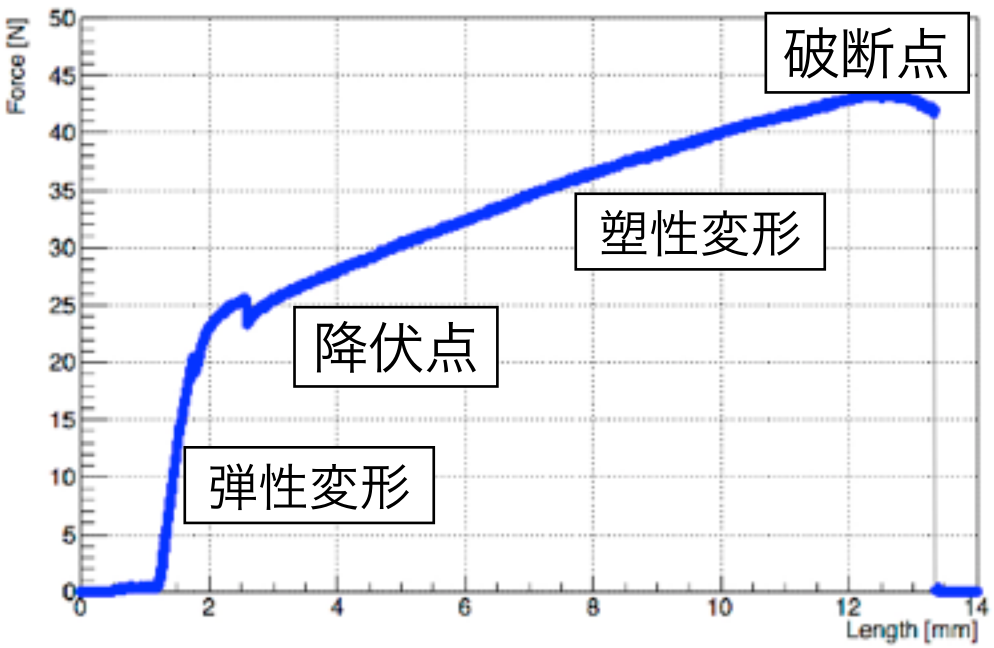
- 機械溶着部は引き裂ける場所がある。
- 手溶着部は簡単には裂けない。

最適パラメータの再探索

パラメータ：温度・時間・圧力、（フィルム枚数、ヒーター方向、…）

測定量：降伏点・破断点、厚み、リーク、（…）

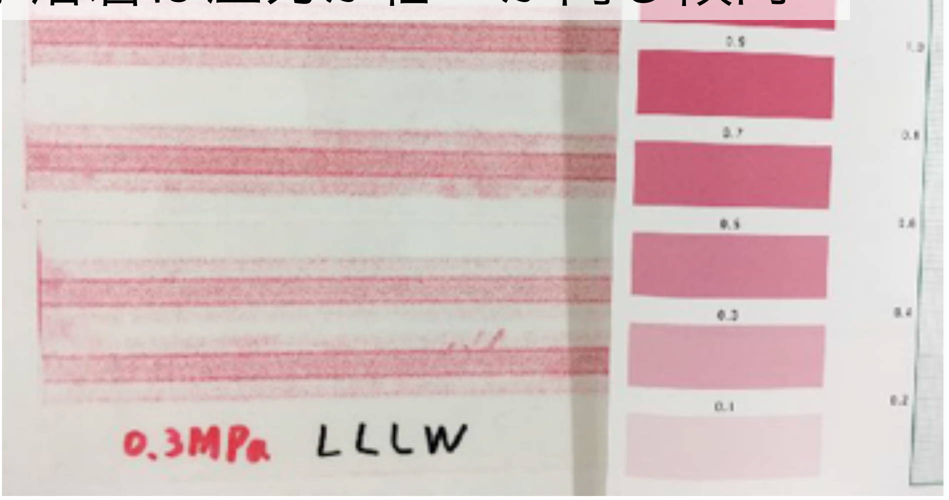
1cm幅での引っ張り強さと伸びの関係



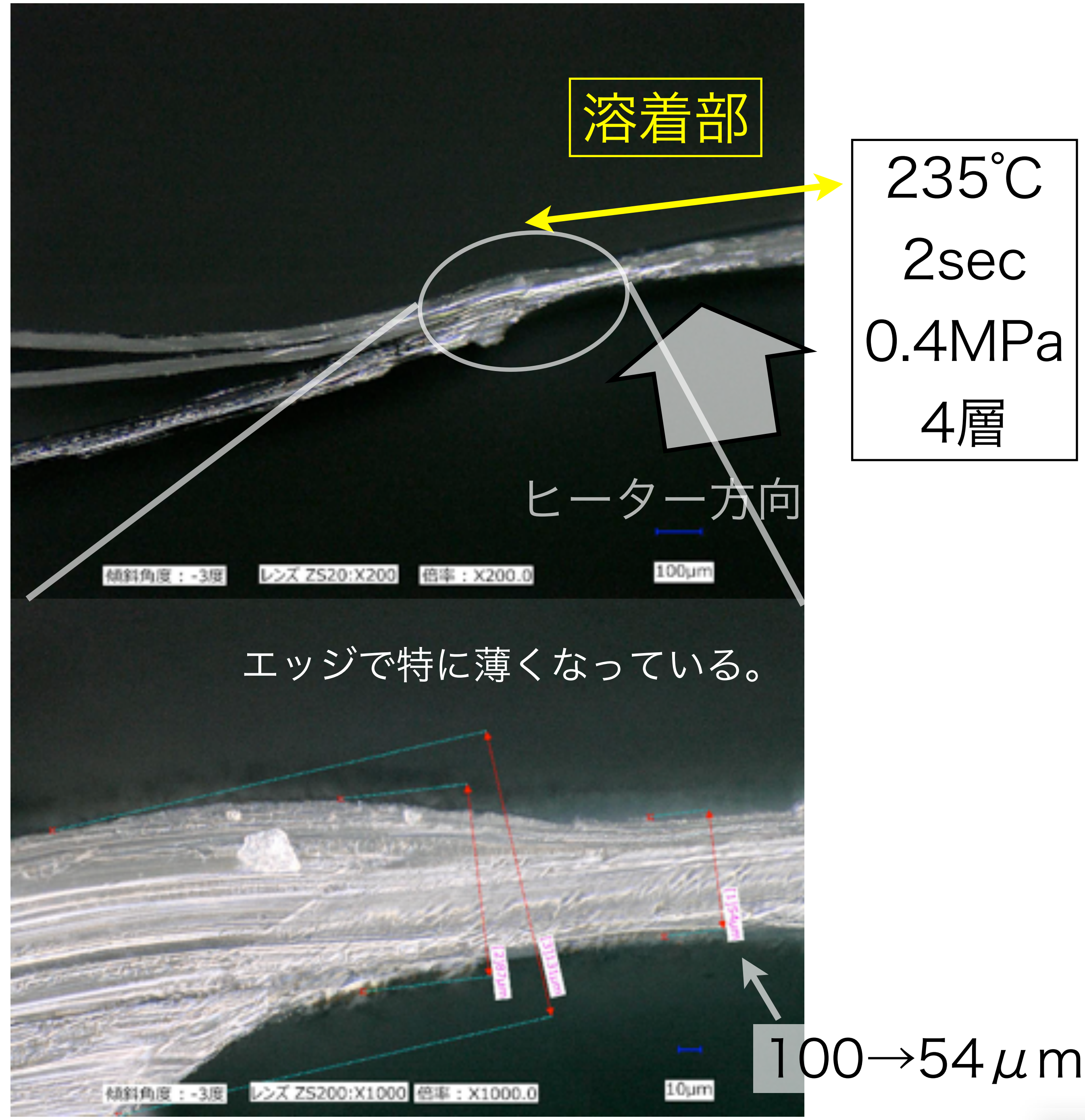
圧力分布の測定（懸案事項）

圧力は溶着線のエッジが高い

手溶着は圧力が低いが同じ傾向

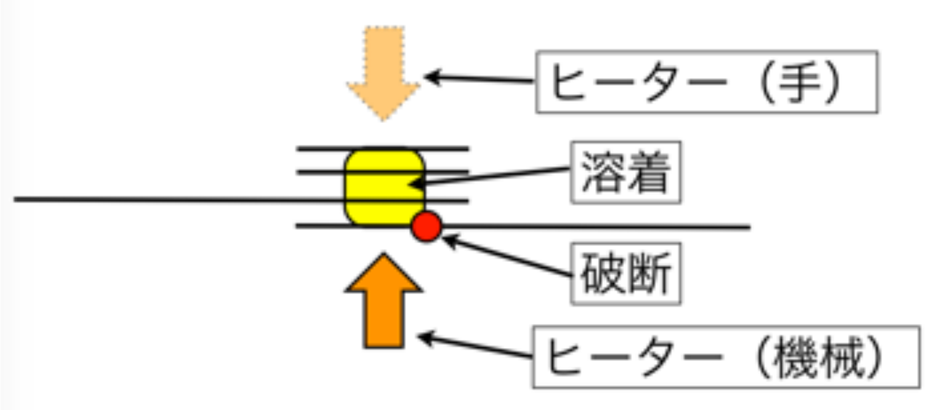


マイクロスコープによる厚み測定



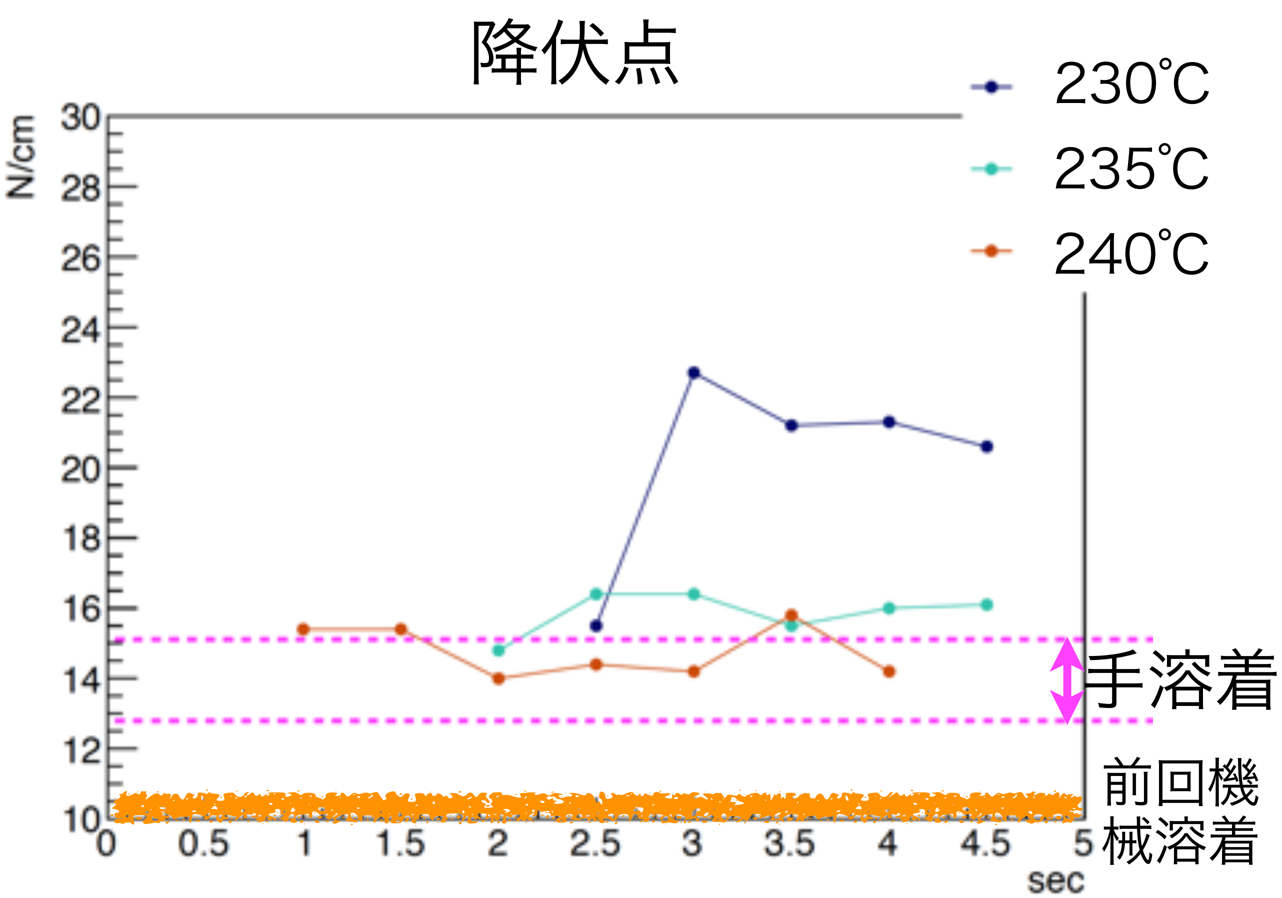
Zen400用で手溶着をした技術者によるレビュー

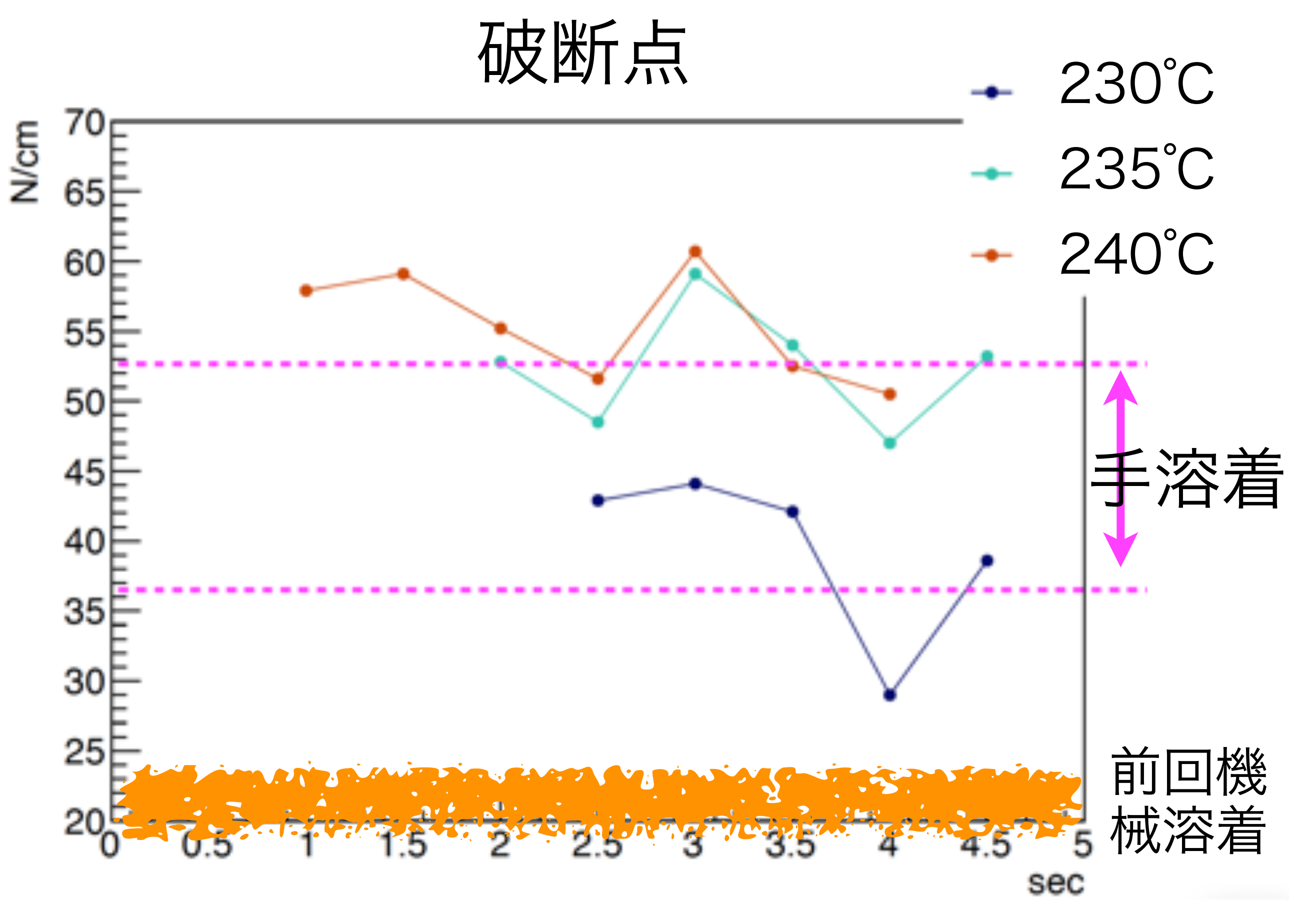
圧力を下げて手溶着と同じ方向
から熱すれば大丈夫でしょう。。



降伏点に着目すると
例：230℃, 3sec, 0.1MPa
破断点に着目すると
例：240℃, 3sec, 0.1MPa

降伏点は、前回比50%~100%増
破断点は、前回比2倍





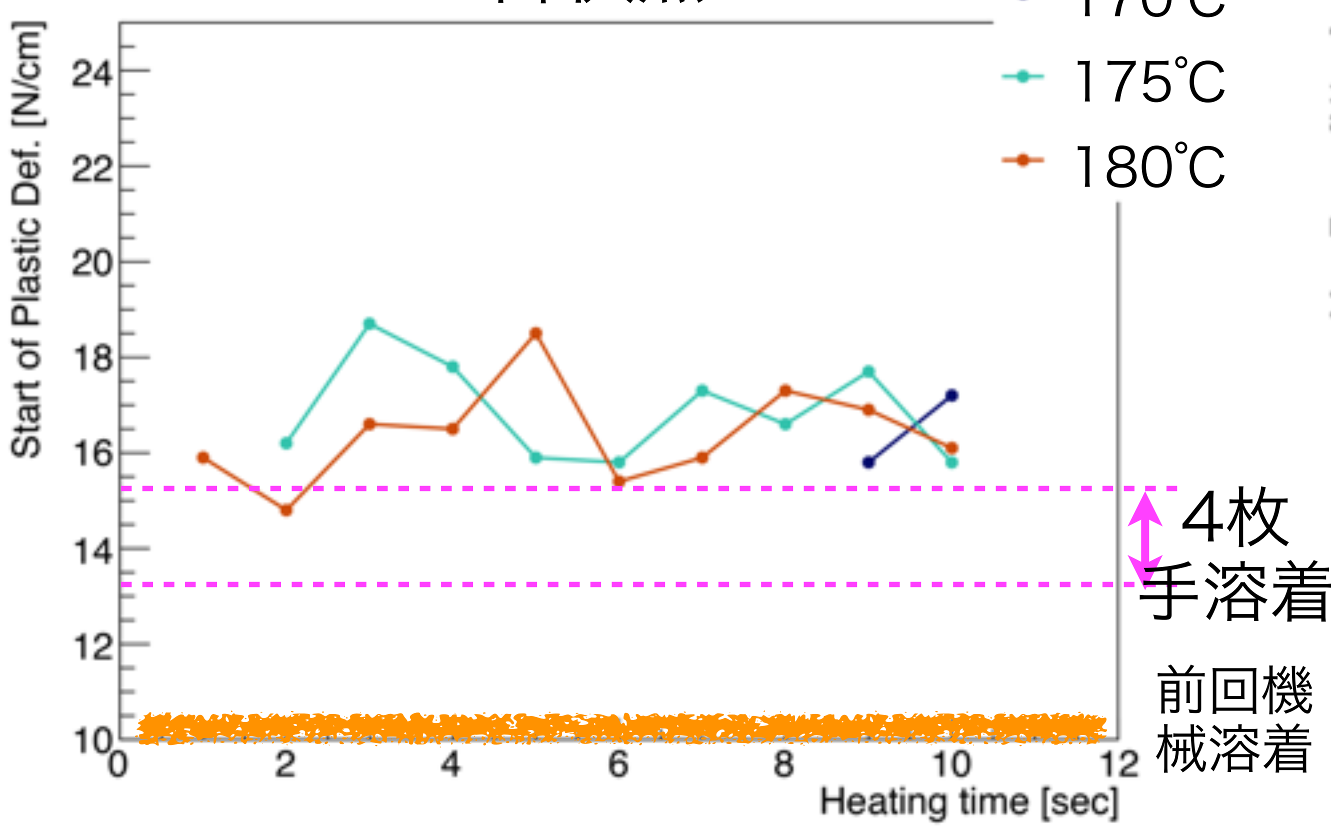
米国の技術者によるレビュー（技術提案）

オリジナル	~230℃	~3秒	4層
新手法	~170℃!	~10秒	2層

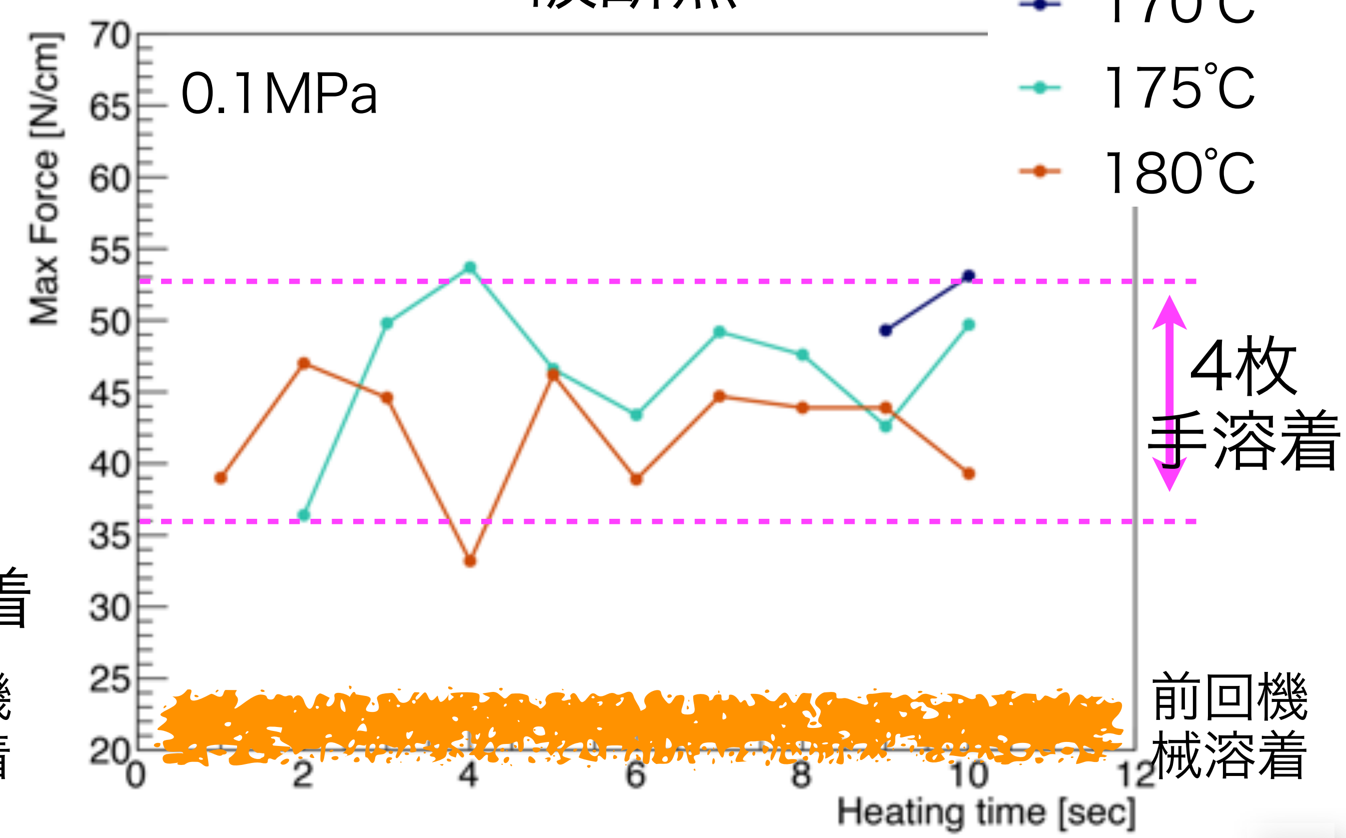
使用する6ナイロンの特性
融点225℃, ガラス転移点40℃
結晶化度30%, アモルファス70%

- 強度は手溶着と比べて遜色ない。
- エッジが強度低下しない。
- 作業手順の大幅簡略化。
- パラメータ調整は機器ごと必要。

降伏点

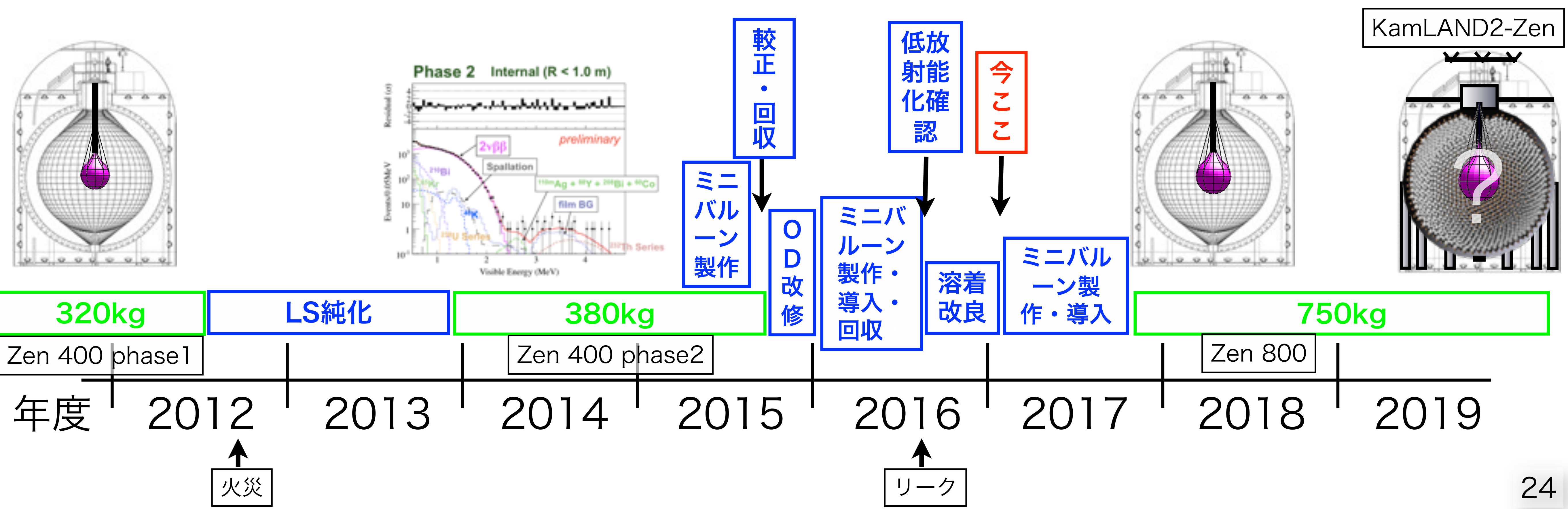


破断点



Zen 800の今後の予定（目標）

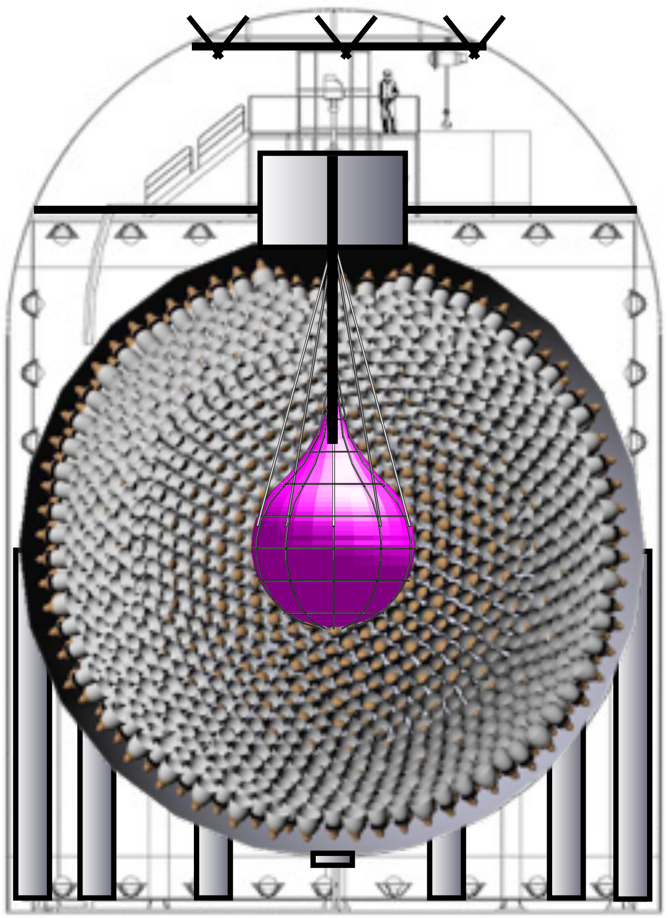
- ６月後半から溶着開始
- ９月までにリークテストも完了
- 10月くらいに導入
- ダミーLSでテスト後、年内にキセノン導入
- 年度内には不純物レベルも分かると期待する。
- KamLAND2-Zenが予算化されるまで、最大5年程度継続。



And more future plans!

Higher energy resolution for reducing 2ν BG

⇨ KamLAND2-Zen



1000+ kg xenon

Winston cone	light collection ×1.8
high q.e. PMT 17"ϕ→20"ϕ ε=22→30+%	light collection ×1.9
New LAB LS (better transparency)	light collection ×1.4

expected σ(2.6MeV)= 4% → ~2%

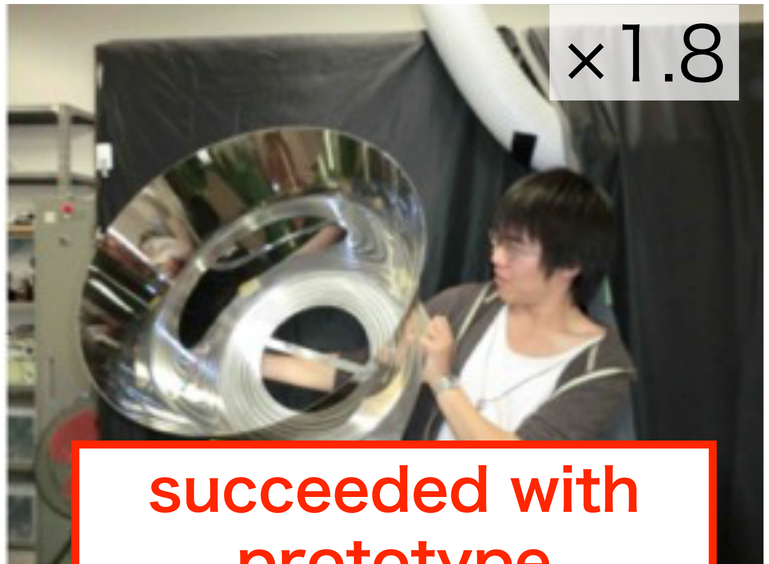
target sensitivity 20 meV

日本学術会議マスタープラン2017に掲載
23-2「極低放射能環境でのニュートリノ研究」

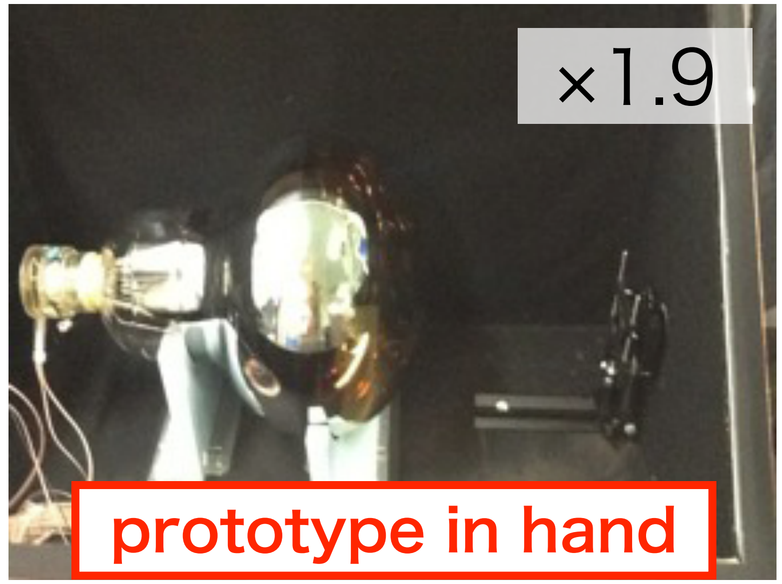
重点大型研究には入れず。。

R&D for KamLAND2-Zen and future

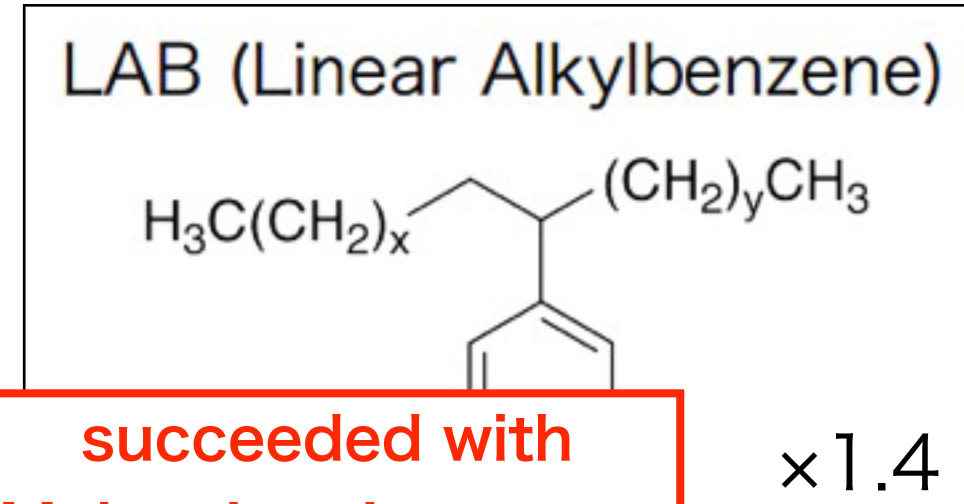
○ winston cone



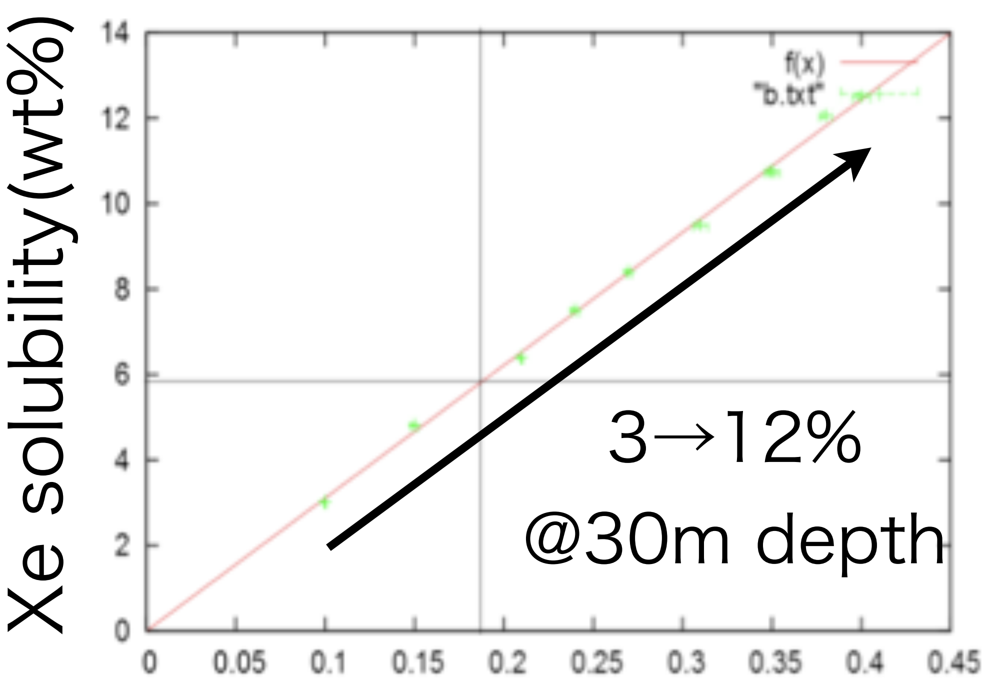
○ HQE-PMT



○ New LAB-LS

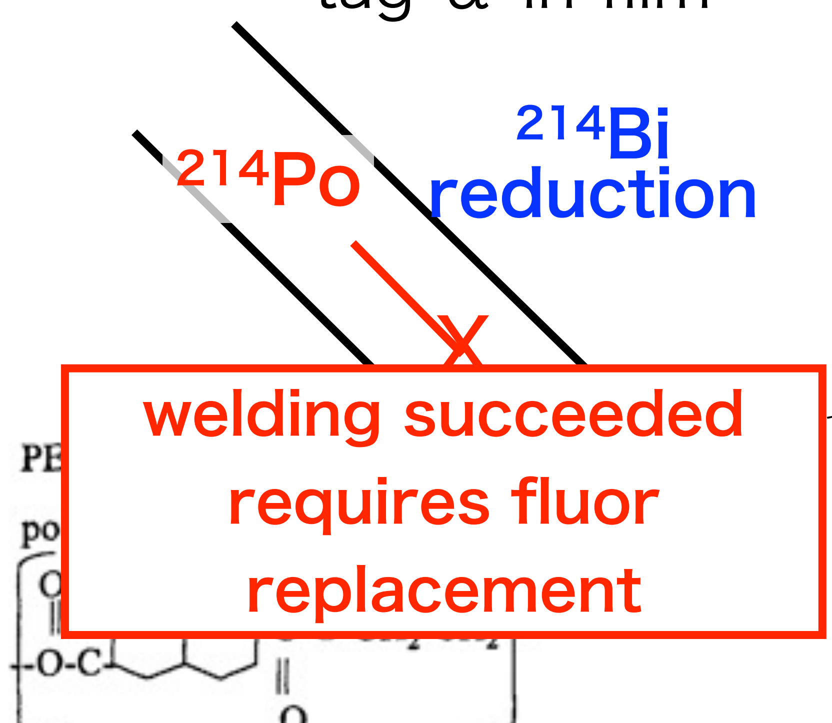


○ denser xenon

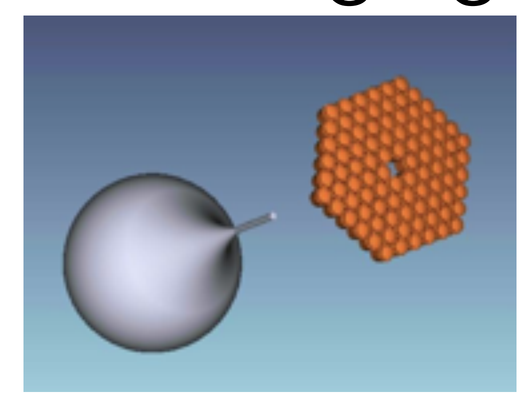


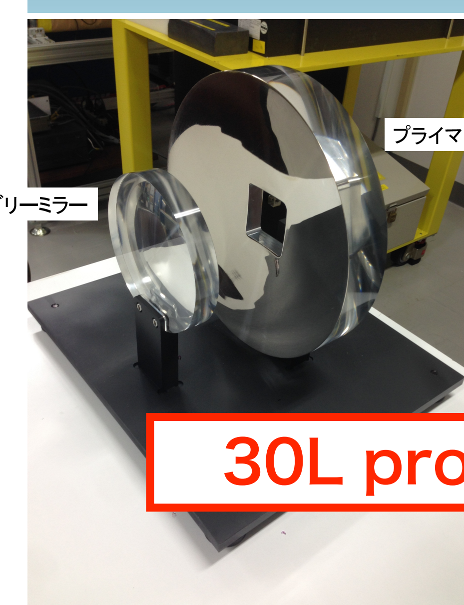
principle confirmed

○ scintillator film



○ imaging





β/γ id.

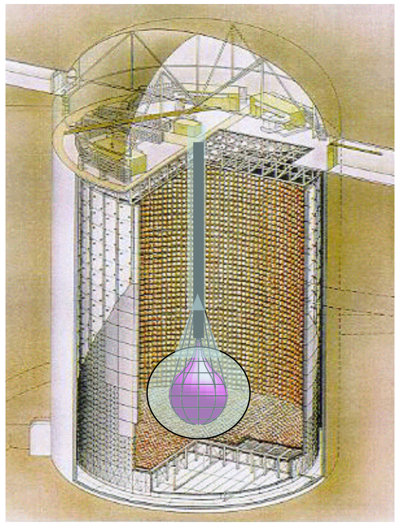
Summary

- KamLAND-Zen 400で手法の正当性を実証。（世界最高感度）

  $T_{1/2}^{0\nu} > 1.07 \times 10^{26}\,\mathrm{yr}$ $\langle m_{\beta\beta} \rangle < (61 - 165)\,\mathrm{meV}$ PRL117, 082503

- KamLAND-Zen 800のクリーン化を実証。Zen 400に対してフィルムの不純物量3分の1から10分の1を実現。
- リーク原因を調査し、溶着手法を改善。1.5から2倍程度の溶着強度を実現し、作業手順の簡略化も可能。
- 目標は今年度内にZen 800を稼働し、バックグラウンドレベルを測定する。目標感度は50meVをきり柳田予測に迫ること。
- KamLAND2-Zen の開発は順調。感度目標20meV

And more?



Super-KamLAND-Zen

in connection with Hyper-Kamiokande

target sensitivity 8 meV

Thank you!